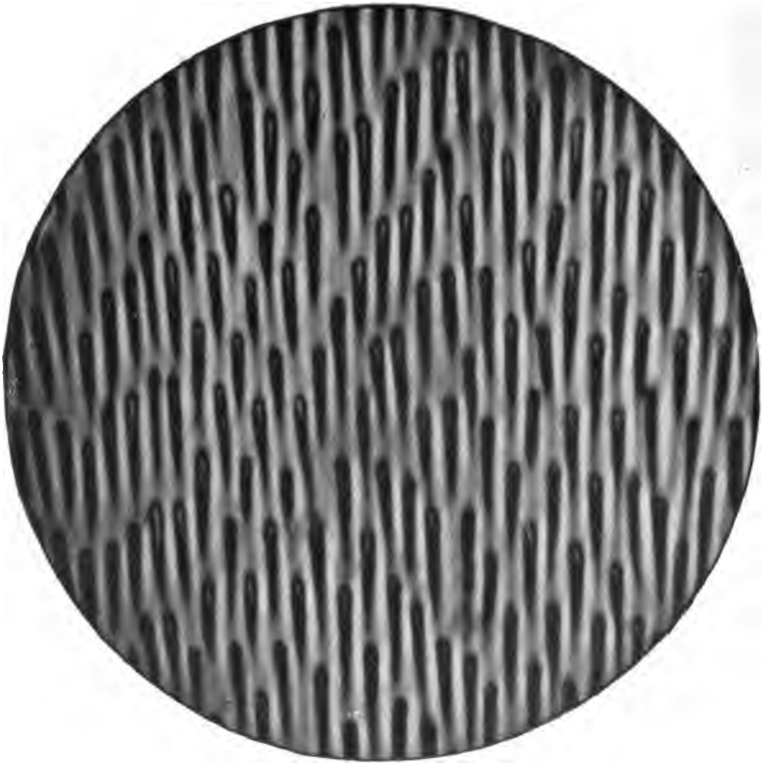
Louis Rominger

Microscopical Praxis.



PHOTOMICROGRAPH

OF THE

TEST PODURA (*LEPIDOCYRTIS CURVICOLLIS.*) x 3000.

BY

H. G. PIFFARD, M.D., NEW YORK.

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Microscopical Praxis

OR

Simple Methods of Ascertaining the Properties of Various Microscopical Accessories

BY

Cheatham

ALFRED C. STOKES, M. D.,

AUTHOR OF "A CONTRIBUTION TOWARD A HISTORY OF THE FRESH-WATER INFUSORIA OF THE UNITED STATES;" "A KEY TO THE GENERA AND SPECIES OF THE FRESH-WATER ALGÆ AND DESMIDIEÆ OF THE UNITED STATES;" "MICROSCOPY FOR BEGINNERS;" "OBJECTS FOR THE MICROSCOPE," ETC.

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Contents.

Illustrations.

Preface.

The writer was recently asked: How is the value of the spaces on the eye-piece micrometer ascertained? What is done with the stage-micrometer when the eye-piece micrometer is in use? And, How can I learn the magnifying power of a simple microscope?

It was these and similar questions which lead to the preparing of this unpretentious little book for the use of those beginning microscopists that are desirous of knowing how to ascertain the matters referred to in these queries, and such other points that are generally unknown by the novice in connection with the various microscopical accessories.

There seems to be an actual need of a book of simple explanations of such processes as the ascertaining of initial magnifying power of microscope-objectives, of the focus of the concave mirror, of the power of the eye-piece, the measuring of the actual and of the apparent field of view, the measuring of the thickness of thin cover-glass, the measuring of the refractive index of immersion-fluids, and other matters of the kind which every amateur microscopist sooner or later is anxious to know, and which the books and the magazines either

entirely neglect, or publish in such a manner as to be inaccessible to the general reader.

It is in the explaining of these uncomplicated but important methods in the use of the microscope that the book has its excuse for being, if it have any. Its author has intended that the inquirer should find in its pages, in the form of a few simply-expressed directions, an answer to his question, instead of writing to some microscopical magazine to ask, for instance, How shall I ascertain the focal length of my pocket-lens? and then waiting several months for some leisurely microscopist to reply, and perhaps waiting in vain.

That the book contains all the points that might justly be expected to be found in it, the writer can scarcely hope; he has not attempted to make a microscopical encyclopædia, but only an elementary praxis of those common things which, at the beginning of his own use of the microscope, he would have liked to know, but could not learn, because the sources of information were then beyond his reach. For the use of all amateur microscopists in a similarly questioning mood, the book is submitted with the author's good intentions.

An attempt has been made to give credit to all those microscopists whose methods have been referred to, but as some of these ways and means are so generally current that they have become common property and their sources have been forgotten, it has not been possible in all cases to discover to whom the credit belongs. If the reader should happen to find some of his own original and cherished methods described without the mention of his name, he may feel sure that the omission is due, not to the writer's intentional lack of courtesy, but solely to his ignorance.

Many, perhaps the majority, of the means here suggested to certain ends are not scientifically and mathematically accurate, and no such claim is made for them; yet they are intended to be sufficiently correct, and the results sufficiently close, for every practical purpose of the non-professional microscopist, for whom they have been prepared and with whom they are now left.

TRENTON, N. J., 1894.

Microscopical Praxis.

The Pocket-Lens.

The pocket-lens is simply a double-convex lens which is usually mounted in a vulcanite frame. There are several varieties in the market, but however they may vary in magnifying power and in appearance, they are all essentially simple double-convex lenses. Each may consist of a single lens, or of several so mounted that one or all may be used at a time, the powers varying according to the combination. With the single lens the magnifying power always remains the same. This is the preferable form. It usually magnifies sufficiently for all practical purposes and it is easily and rapidly used; while with the combination form the power is often inconveniently great and the field of view correspondingly limited. The working-distance, too, or that distance between the lens and the object when in focus, is also much shorter than with the single, low-power pocket-lens.

Three simple double-convex lenses usually form the combination pocket-lens, each giving a different magnifying power, the highest being in use when the three are employed together, the combination then acting as does the single lens. In such cases there is usually a diaphragm inserted between the highest-power glass and the next powerful, in order to obstruct the passage

of the rays of light that pass through the margin of the lens, and which do not come to the same focus as those that pass through the centre. This spherical aberration, as it is called, being especially noticeable with high-power pocket-lenses. It exists in all forms, except in the achromatic triplet, in which it is corrected by the use of a combination of lenses cemented in proper position by the optician.

The more the lens magnifies the closer it must be brought to the object in order to focus it. These combination lenses are therefore not so pleasant to use as are the single forms. When employing the entire combination the highest-power lens should be nearest the object to be examined, while either surface of the single lens may be toward the object.

A single lens magnifying about five diameters and having about two inches of focal distance is an excellent one for ordinary use. If an achromatic triplet should be desired, and it is an admirable thing to possess although rather expensive, one with the half-inch focus should be selected, as it will then magnify about twenty diameters and be amply sufficient for all kinds of field-work.

To Measure the Focus of the Pocket-Lens.

To ascertain the focal distance of the lens by daylight, focus the bar of a window on a distant wall, the

distance from the window being as great as possible, at least the width of the room. Move the lens to and fro before the wall opposite the window until the bar, the curtain-fringe or a tassel is sharply in focus on the white surface. Then measure the distance of the lens from the wall, and that distance will be focal length. The image will be small, and it should be perfectly sharp and distinct.

At night remove the lamp as far as possible from the wall and use the edge of the flame. In this case the focal point will be represented by a minute spot of light of great brilliancy, and the experimenter should be sure that the spot is as small as possible, and that there is not an indistinct haze or halo around its margin. Measure the distance as in the other experiment. In both cases take care to have the lens parallel with the wall. If it is held obliquely, the spot of light will be irregular in form and indistinctly defined. This is especially to be remembered in the evening, when the little spot should be perfectly circular, and intensely bright.

To Ascertain the Magnifying Power of the Pocket-Lens.

The opticians have found it necessary to select an arbitrary distance at which vision with the naked eye shall be measured, a ten-inch space having been agreed

upon. The standard bodies of British and of American microscopes are of that length, and the best objectives are corrected for such tubes. The drawing and the measuring of objects under the compound instrument are commonly made at that distance from the eye-piece, and the pocket-lens comes in for similar treatment, and for the same arbitrary reason.

To measure the magnifying power of this lens place it on a support so that the upper surface of the glass shall be ten inches above the table, and below it spread a sheet of white paper. Have at hand a rule divided to the tenths of an inch. Hold the rule at right angles with the microscopist's body for convenience of manipulation, that is, with its width parallel with his width. In the right hand lift the ruler into focus under the lens and hold it there steadily, keeping the head immovable in one position, and with one eye, preferably the left eye, closed. When the object is in focus, open both eyes and the lines will appear to be projected on the paper. With a pair of dividers in the left hand ascertain the apparent width of one of these spaces and measure that distance on the rule, when each tenth-inch between the divider's points will represent one diameter in magnifying power. If the space occupies five-tenths, as it probably will with a lens having a two-inch focus, the magnifying power will be five diameters; that is, the object will be enlarged five diameters in length and in width, or twenty-five times.

A lens of any kind magnifying ten diameters is said to magnify one hundred times, or ten diameters in each direction, "times" representing the square of the "diameters," and the diameters the square-root of the times. If this fact is recollected there is no danger of being deceived by the ridiculous claims for power

made for their lenses by some dealers, who are careful to express the amplification by "times," with the intention to lead astray the unsuspecting, extolling a lens, for instance, because it magnifies "a thousand times," which is only one hundred diameters, not a high power with the compound microscope, but utterly impossible with the simple pocket-lens.

A Test for the Pocket-Lens.

Mr. Julien Deby, who has suggested the following test for the excellence of a pocket-lens, remarks, that although many objects are accessible for the determination of the merit of the medium-power and of the low-power magnifying glasses of the compound microscope, none is on record for that most useful instrument to the naturalist, the hand-lens. This needed test he considers to be the elytron, or wing-cover, of the aquatic beetle *Gyrinus marinus*. The lens should show not only the longitudinal rows of large dots, but also the fine intermediate punctations, the elytra of the male beetles of the genus being more difficult of resolution, since the markings are there finer than those on the wing-cases of the females. But unfortunately the species of "whirligig" beetle selected by Mr. Deby is not found in this country. Other forms are here however, and as all the species so closely resemble one another that entomologists differ in their opinion as to

what constitutes a distinct species, it is probable that the wing-cases of almost any form will answer the purposes of a test.

To enable the microscopist to identify the forms that he may find, and whose elytra he may experiment with as a test for his pocket-lens, the following key to the species is given. It was originally published in "The Journal of Microscopy," and is reproduced here somewhat changed in form.

Key to the Species of the aquatic Beetle Gyrinus.

A. Underside entirely rusty-red (*a*).

B. Underside wholly or chiefly black, legs reddish (*b*).

a. Punctures on elytra scarcely feebler toward the suture, *G. minutus*, Fab.

a. Punctures on elytra finer toward the suture, *G. urinator*, Ill.

b. Reflexed margin of thorax and elytra reddish (*c*).

b. Reflexed margin brassy black (*f*).

c. Body ovate or oval (*d*).

c. Body elongate-oblong with nearly parallel sides, *G. bicolor*, Payte.

c. Body oblong-ovate (*e*).

d. Punctures on elytra distinctly finer toward the suture. *G. natator*, Sch.

d. Punctures scarcely finer, *G. suffriani*, Scrip.

e. Interstices on elytra impunctate, *G. distinctus*, Hub.
e. Interstices indistinctly punctured, *G. caspius*, Men.
e. Interstices closely and distinctly punctured, *G. colymbus*, Fr.
f. Punctures on elytra scarcely finer toward the suture, *G. marinus*, Gyll.
f. Punctures much finer toward the suture, *G. opacus*, Sahlb.

Our well-known species is common and abundant on the surface of still waters in the spring and the summer, floating together in companies, or swimming rapidly singly and often in circles, their vivacity making them rather difficult to capture without a net. They have a not unpleasant musk-like odor when held in the closed hand. They are everywhere known as the "whirligig beetles."

The Stand and its Parts.

The compound microscope includes the eye-piece and the objective, with the brass parts which support the mirror and the optical portions; that is, it includes the entire instrument as prepared for the examination of objects, while the stand is only the brass part with the mirror and usually the eye-piece. To convert the

stand into a microscope the addition of an objective is essential. It is well to remember the distinction between these terms, especially in talking with the dealers. If you ask a dealer for a microscope, he will anticipate the sale of not only the stand but of a series of objectives as well; but it is often to the purchaser's advantage to buy a stand of one manufacturer and the objectives from another. The following is a list of the parts of the stand, with the definition of each.

FOOT OR BASE:—The part on which the entire instrument rests, usually in the form of a low and flattened tripod.

PILLARS:—The upright, cylindrical rods attached to the centre of the foot and supporting the portions above. Many stands have only a single pillar.

ARM:—The part, usually curved, attached to the pillars by means of a joint, so that the working-portions may be inclined at the convenience of the observer. The upper frontal end of the arm carries the body.

BODY:—The movable tube to which are attached the magnifying or optical parts.

DRAW-TUBE:—An additional, movable tube within the body, whence it may be withdrawn at the will of the microscopist to increase the magnifying power, or for other purposes.

EYE-PIECE OR OCULAR:—The short tube containing an upper and a lower lens, and fitting loosely into the upper end of the body, or of the draw-tube. It is so called because it is near the observer's eye when the microscope is in use.

OBJECTIVES:—The compound magnifying lens applied to the lower end of the body. It is so named because it is near the object to be examined when the microscopist is working with the instrument.

FOCUS:—The position of the lenses in which the object is seen most distinctly. Seeking this point by moving the lens closer to the object or further away, is called focussing.

FIELD OF VIEW:—The circular, lighted space seen by looking through the microscope. The object to be examined, when it is in this space, is said to be in the field.

COARSE ADJUSTMENT:—The means by which the body is moved up and down rapidly, and the objective brought into approximate focus. In the cheaper stands this is accomplished by sliding the body through a collar which is immovably attached to the arm. In other and better grades it is by rack and pinion.

RACK AND PINION:—The rack is the straight, narrow piece of metal at the back of the body, with cogs or teeth on its edge. The PINION is the toothed wheel on the arm; it lifts the body by its rotation and by the action of its "leaves" on the rack. It is usually not visible unless the body is taken off the arm.

FINE ADJUSTMENT:—The slow movement which brings the objective exactly into focus. It is accomplished by the action of a fine-threaded screw, at the back of the arm in the better class of modern instruments, or at the lower end of the body in the older and less praiseworthy stands. It is also sometimes under the front of the arm, or even attached to the stage and moving it.

STAGE:—The thin, circular or oblong plate of metal or of glass attached to the lower, frontal end of the arm, and used to support the object to be studied. It is pierced by a central opening for the passage of the light that illuminates the object.

SPRING CLIPS:—The two, narrow, curved strips of metal attached to the back part of the upper surface of the stage, and which hold in place the object-carrier or the glass slip.

SLIP:—The strip of glass, usually three inches long by one inch wide, on which the object to be examined is "mounted." It is placed under the spring clips, when they are present, as they are not on all stands. It is held loosely in position and is easily moved to and fro under the objective by the fingers, or by movement of the whole stage when the spring clips are absent.

SLIDE:—The slip with the object prepared for examination. The addition of the object changes the slip into the slide. The object is usually covered with a square or a circular piece of thin glass made for the purpose.

DIAPHRAGM:—The circular, rotating disk of metal pierced by openings of various sizes and placed beneath the stage. It is used to modify the light, its different apertures being turned below the stage-opening for that purpose. In microscopical literature and conversation any disk with one or more apertures is a diaphragm. Such disks are to be found in the body-tube, in the eye-piece and in some other parts of the optical accessories.

STOP:—A metal disk with a central, circular piece to obstruct the passage of light, and supported by narrow, radiating arms; or a metal disk with a semi-circular or rectangular portion cut from one side, and used to obstruct all light except that which passes obliquely through the opening.

MIRROR:—The silvered glass that reflects the light through the object or upon it, and through the objective, the body and the eye-piece. It is attached movably

to an arm at the back of the stage by means of the mirror bar, and has independent movements of its own. It should have both plane and concave surfaces in the same mounting.

SUB-STAGE:—Those parts, except the mirror, which are below the stage and intended to carry various accessories to affect the illumination. In the best stands the sub-stage is attached to the arm by a movable sub-stage bar; in others it is borne on the mirror-bar, while in the cheaper forms it is attached to the under surface of the stage. From the lowest priced instruments it is usually absent, yet it should always be present in some form, as it is of great importance in many kinds of work, since certain essential accessories cannot be used without it.

MILLED HEADS:—The disks, roughened or milled on the edges to give the fingers a firm hold, and attached to the fine-adjustment screw, to the pinion of the coarse adjustment, and to the various sub-stage apparatus of first-class stands.

The Body-Tube.

Many stands with the body-tube about six inches long have a draw-tube by which to increase it to the standard length of ten inches. Most instruments of this kind have the short body lined with cloth, an ar-

rangement that for a time ensures a smooth and easy movement of the draw-tube. Soon however, especially if much used, the latter begins to move less smoothly, until finally it may demand considerable muscular effort and both hands. The difficulty is caused by the roughening of the cloth lining, which must be remedied before the tube can again be moved easily. To do this, take out the draw-tube and heat it until it is so hot that it cannot be held without some discomfort, and gently force it into the body where it should remain until cold. This in effect irons the lining, which the experimenter must be careful not to burn. If one ironing is not sufficient the heating should be repeated.

It not rarely happens, too, that after the cloth-lined tube has been used for some time, the draw-tube will slowly slip downward, urged forward by its own weight alone. The object will gradually become dimmer until it will slowly fade away, unless it is followed up by a change of focus, or unless the draw-tube is extended. This is even a greater annoyance than to have the cloth lining of the body too thick to admit the draw-tube, as it continually interferes with the appearance of the image. To correct it, loosen the texture of the cloth by the fingers alone, or by teasing it out gently with the forceps.

The inside diameter of the opening in the lower end of the body and the outside diameter of the screw-end of the objective are about three-fourths of an inch. This is the society screw, so called because first suggested by the Royal Microscopical Society of London. For objectives as commonly made, it is amply sufficient, but for a few exceptional ones it has been found too small. A few opticians make a few objectives

whose angle of aperture is so uselessly great, and the diameter of their component lenses so uselessly large, that a special screw is demanded on the end of the body. This, at the suggestion of Dr. W. W. Butterfield, of Indianapolis, is made about one and one-fourth inches in diameter. It is called after the inventor's name the Butterfield screw, and is to be found on first-class American stands, which have almost every microscopical convenience, being placed above the society screw so that, to use it, a part of the lower end of the body must be removed. It is not on the cheaper stands, and is not needed. Indeed it is a worthless thing anywhere. The society screw is an indespensable adjunct of every body-tube, and is found on all American and English stands, however small and cheap they may be. And when the reader goes to the optician to select a stand, he will find it to his advantage to recollect the size of the society screw and its position.

In this connection there is one rule to be remembered, and it is without exception. It is that any body-tube with a screw on its lower end of a diameter less than three-fourths of an inch should be rejected without a moment's hesitation. And any objective with a screw on its upper end of a diameter less than three-fourths of an inch should be rejected even more speedily. Any stand or any objective without the society screw may safely be set down as a good thing to be avoided, and the reader may also justly view with suspicion any objective which must have an adapter to fit it to the society screw of the stand.

In some first-class American stands a useful contrivance is applied to the lower end of the body, and named 'the safety nose-piece.' It consists of a short

tube sliding easily within the body, and pressed upon by a spiral spring so that when forced upward, the pressure of the spring tends to return it to its former position. Its use is to protect high-power objectives and also the object. High-power lenses usually have a short working-distance, so that there is danger, when focussing, of touching the front of the lens against the glass slip, a thing that every careful microscopist is anxious not to do, since the thin-glass cover over the object may be cracked, or the lens scratched or broken, a much more serious matter than the breaking of a cover-glass. But should such an accidental contact occur, before injury can be done the safety nose-piece will slide upward, at once relieving the pressure on the objective and calling the microscopist's attention to the danger. But any microscopist that will focus an objective while looking through it deserves to injure it.

Every objective, it makes no difference what its focal length may be, should always be focussed while the microscopist is looking under it, not while he is looking through it. In the last-mentioned position the finishing touches may be given by the fine adjustment, if necessary, but in all other events the objective should be gently racked down toward the object while the microscopist is looking across the slide and under the descending lens. In this way he can see how near the objective is to the slide, and can guard it from danger. Then while looking through it he should rack it upward until it is in accurate focus, if it is a low or a medium power, or if a high-power the focussing should be accomplished by a few touches to the fine-adjustment screw. In no instance should any objective be focussed downward, not even the four inch, while the observer is looking through the instrument.

Another interesting and often useful device on first-class American stands and on a few foreign ones, is the scale and vernier on the side of the body and on the arm of the instrument, for the measurement of the working-distance of objectives. It is never found on smaller and cheaper stands, where it might well be applied without great additional cost, and be used to assist the beginner in focussing his objectives, or in measuring the working-distance of his lenses.

The Draw-tube.

On the majority of stands a draw-tube will be found within the body if the latter is of the standard length of ten inches. On those whose body is shorter than ten inches, the draw-tube is used only to make the extension to the standard length, and no additional tube will be on the instrument. The length of the draw-tube is usually almost that of the body, so that it will lengthen the latter enormously when fully extended, and correspondingly increase the magnifying power. Its upper end commonly projects somewhat beyond that part of the body, affording a means of manipulation, and for carrying the eye-piece.

The lower end bears a diaphragm whose aperture sometimes contains the society screw, so that very low-

power objectives may be placed there and used while entirely within the body. This is often a great convenience in the employment of such objectives as the four, or three inch, which have such an exceedingly long working distance that occasionally the body must be raised so high above the stage that it will run off the rack before the focus is obtained, but if the objective is on the diaphragm of the draw-tube it may be approximately focussed by pulling out that tube, the focussing being completed by the rack and pinion on the body. These low-power objectives are at times very useful in the study of large objects, where not much amplification is desired.

What are styled 'Student's stands' often have the draw-tube diaphragm supplied with the society screw. It is not restricted to first-class instruments, as it is almost a necessity on any stand, for it not only may carry the low powers, but also the amplifier, and the analyser of the polariscope. As a diaphragm of some kind must always be in the tube, and as the society screw can add but the veriest trifle to the cost of the stand, the purchaser might do well to seek an instrument with this convenience.

The draw-tube is also often externally graduated to parts of an inch or of centimeters or both, so that the distance to which it is extended may be recorded and a desirable result be reproduced at any future time. The only graduation on the cheaper stands is a single circle engraved at the point to which the tube must be extended to make the body of the standard length.

When the part is to be drawn out, do so with a strong and steady pull, holding the body firmly in position at the same time, otherwise it may be run off the rack and entirely off the arm. Do not turn the draw-tube from

side to side while extending it. The latter method puts a severe strain on the rack and pinion, and on the fine adjustment if it be at the back of the arm. When it is to be pushed in, grasp the milled head of the pinion, or hold the body so that the latter can not move, while the tube is slowly and steadily pressed down. If these precautions are not taken, and the objective is on the body, it may be forced against the slide, or the air compressed within the body may throw out the eye-piece.

Increase of Magnifying Power by the Use of the Draw-tube.

Every increase in the length of the body-tube increases the magnifying power of the objective by increasing the distance between the lens and the eye-piece. The following tabulated statement of the increase in power to be added to the original amplification for each inch to which the draw-tube is extended is only approximately correct, but it is near enough for all practical purposes. It was originally calculated and published by Messrs. R. and J. Beck to accompany their list of British microscopes. The results will not hold good with the objectives or with the oculars of all makers, since all A, B, C, eye-pieces have not the same power.

Objective. Focal length.	Add for each inch of draw-tube with eye-piece,		
	A (2 in.)	B (1½ in.)	C (1 in.)
4 inches.	1½ diam.	3 diam.	5 diam.
3 "	2 "	4 "	6 "
2 "	4 "	6 "	8 "
1½ "	5 "	7 "	12 "
1 "	5 "	15 "	20 "
⅔ "	8 "	14 "	25 "
4/10 "	14 "	24 "	34 "
¼ "	24 "	42 "	63 "
⅙ "	18 "	35 "	60 "
⅛ "	50 "	85 "	140 "
1/10 "	60 "	100 "	180 "
1/20 "	80 "	150 "	300 "

The Coarse Adjustment.

This part consists of the rack on the body-tube, the pinion with its cogged wheel acting in the depressions or teeth of the rack, and the milled heads on each side by which it is manipulated. Its action is to raise or lower the body rapidly so that the objective may be approximately focussed, or be lifted above the stage when the slide is to be placed in position, so that the two may be in

no danger of coming in contact, with the possible injury of one or of both.

The rack should be as long as possible, so that the body's movements shall be ample for all exigencies. A length of from four and one-half to five inches is none too great. And its motion should be, as some one has said, "as smooth as oil." A coarse-adjustment mechanism that is noisy when in action, that rattles and gnashes its teeth, or one that makes the image change its position by throwing the body out of centre, should be rejected. The only place for such a thing is a shelf in a museum of microscopical antiquities. The action should be noiseless, perfectly smooth, and the bearings so firmly in place, that the microscopist shall have no fear that a heavy objective may force the body to run downward by its weight and by the absence of resistance in the coarse-adjustment mechanism, an accident that has happened. This undue looseness, however, may occur after constant and prolonged service, and a remedy is usually provided by the optician, who places screws in such a position on the arm or elsewhere, that by tightening them the pinion-bearings are tightened, and the trouble is corrected for a time. Every stand, even the best, is liable to this annoyance in a greater or lesser extent.

Some of the cheaper stands have no coarse adjustment. The body is then encircled by a collar through which it moves when actuated by the hand, the focus being obtained by pulling and pushing on the tube. This is a very inconvenient and undesirable arrangement. It is awkward, since the friction is often so great that the whole stand will move out of position before the body will budge, and frequently, more frequently than not, even when the foot is heavy

enough to keep the instrument firmly on the table, both hands are needed to manipulate the body. It is dangerous, too, since under the circumstances, the body has the obnoxious habit of suddenly slipping further than the microscopist intends, stopping only when it crashes againt the slide, where it usually grinds and and crunches cover-glass and objective with apparently fiendish glee. A stand without a coarse adjustment by rack and pinion is a good stand to be permanently left with the optician. No fine microscopical work can be done with an instrument whose body slides through a friction collar. That arrangement may be cheap, but it is also a torment and a peril.

The Fine Adjustment.

When the objective has been imperfectly focussed by the coarse adjustment, its position must be often further changed until the image becomes clear and bright, and the outlines as distinctly and sharply defined as the lines in the best steel-engraving. This is accomplished by means of the fine-adjustment screw, which, in the older stands, will be found on the lower end of the body, at the front; on some of the oldest models and on a few of the newest, it will be attached to the stage, but in the best of the more recent it is at the back of the arm.

If the fine-adjustment screw is placed on the nose-piece, the parts will sooner or later work loose, and then every time the milled head is touched the body-tube will wabble and the image dance. And the fine-adjustment screw is touched very often. During an observation the microscopist moves the stage with one hand, and keeps the fingers of the other on the adjustment screw continuously, constantly altering the focus slightly, so as to judge of the structure of the object by the changes in the appearance of the different optical sections practically cut by the objective.

But the most serious objection to the older form, in addition to what has been previously mentioned, is that every movement of the fine-adjustment screw changed the length of the body and altered the magnifying power, which was therefore never the same for two successive moments. With the lower powers this was scarcely observable, but with high powers it became almost conspicuously assertive. And during the use of the micrometer for the measurement of the microscopic objects, it was a menacing danger, since the value of the micrometer spaces was changed with every turn of the fine-adjustment screw. With the mechanism in the arm, all this annoyance is done away with, since every movement of the screw moves the entire body including the objective and the eye-piece. If properly made it has no lost motion, and no side movement. It responds immediately to a touch of the finger, moving the body directly upward or downward with no lateral play, so that the image, even under the highest powers, does not seem to change its position from side to side, a fatal defect if present. The screw is usually and preferably placed vertically at the back of the arm, within easy reach of the fingers as the mi-

croscopist's elbow rests on the table; but some makers place it under the front of the arm, at the side, or even at the back but in a horizontal position or almost at right angles to the optic axis, that imaginary line drawn through the centres of the mirror, sub-stage, stage, objective, body and eye-piece.

The milled head of the fine-adjustment screw on all first class stands, and on some of the less expensive, notably on Messrs. J. W. Queen & Co.'s Acme No. 3, has the upper surface graduated for the measurement of the thin glass always covering microscopic objects when permanently mounted. This glass varies a good deal in thickness, and since its presence influences the action of the objective, it is often important to know just what that thickness is. The value of each graduated space on the wheel depends upon several contingencies, seldom being the same in any two instruments by different makers. What that value is the dealer will tell the purchaser if asked. On my own stand the distance between two lines of the graduated surface is equal to an elevation or depression of the body-tube for the one one-thousandth of an inch.

The Stage.

The stage should always be firm and steady under pressure, but the pressure should be applied judiciously. All microscope-stages, even those on the best stands by Mr. Bulloch, Mr. Zentmayer and others, will respond to the pressure of the thumbs, and be sufficiently depressed to carry the object out of the focus of a medium-power objective. The stage that responds the least is the best, but perfection in this regard seems beyond our reach. Neither is it absolutely essential. The thumbs never press on the stage, unless they are delirious. No heavy objects are placed there. No sane microscopist would put a cobble-stone on his stage. The optician may be trusted to give us the best that the conditions of the problem will allow, and the amateur purchaser need never test the stiffness of the stage by the weight of his arms and shoulders transmitted through his thumbs. If he does, he will deserve to test the weight of the dealer's arms and shoulders transmitted through a club.

The stage should be as thin as is consistent with the proper stiffness and steadiness. This is needed to allow for certain effects of illumination. It sometimes happens that an object must be studied by what is called oblique light, that is, the mirror must be so arranged below and to one side of the object, that the reflected light shall impinge upon it obliquely, and occasionally very great obliquity is needed, which can be obtained only when the stage is thin, since a thick stage and a consequently deep aperture in the centre, would prevent very oblique rays from passing through to the object. Many "Students'" stands are faulty in this respect, the makers seeming to think that since oblique light is needed only in somewhat advanced work, the

beginner will not care for it. But I believe in offering the beginner advantages which he may not at first appreciate, but which he will at last live up to. The æsthetic craze of striving to "live up to" a blue china jug has happily passed, but the effect of living up to one's privileges remains, and the effort should be even the beginner's.

On every stage there should be some kind of movable plate on which the slide shall be placed, the whole moving easily under the impulse of the fingers. Many stands, the majority of so-called Students' stands, have no such plate, spring clips being substituted, the slide being placed under them and moved about by the fingers. This arrangement answers well, provided the clips will themselves remain permanently in position when the slide is manipulated. The fingers are soon educated to perform the most delicate movements, guiding the slide by the gentlest pressure, and speedily learning to keep even a living and lively microscopic creature in the field; but to be able to do these things, the spring clips must not press too heavily on the slide, and they must especially be firmly or immovably fixed in their sockets. As a rule, they are fitted so loosely into the holes provided for them on the stage, that scarcely more than a breath is needed to move them. The result is, that during the constant manipulations of the slide, they are gradually urged more and more to one side or the other, until finally they strike the edge of the cover-glass, push it out of place and, it may be, ruin the object. The microscopist's eye is engaged at the ocular, and his attention is concentrated on the image, so that he cannot pay special heed to the spring clips to see that they are not threatening his cover-glass. The Griffith-Club stand is in this respect a model

instrument. With it the spring clips are made after a new and entirely original form, so that there is absolutely no danger that they will turn and rend the cover. If all stages having spring clips could have them after Mr. E. H. Griffith's model the benefit would be great. But if the dealer offers a stand with very loose clips, reject it until he remedies the defect by fastening them in their sockets. Then manipulations as delicate as any to be made anywhere may be made with the slide under them; but a stand with loose clips is a delusion and a snare.

For special studies special stages are made. Warm stages are used, the warmth being produced by heated air, electricity, hot water or by heated metal plates. Some complicated arrangements are described which are often interesting and amusing, for at times it would seem as if the inventors of these queer devices put down on paper what they think should be useful, if somebody could make them successful. They have dial plates attached, and thermometers, and spirit lamps, and electric batteries, and steam cylinders, and boilers with a multiplicity of rubber tubes, all of which, with many others for cooling objects, for subjecting them to the influence of gases, and for other purposes, are doubtless more or less useful in their particular departments, but they need not detain us now, as the beginner will not need them, nor the advanced microscopist, either, I imagine.

One of the most delightful of microscopical luxuries, one which in some cases is an absolute necessity, is a mechanical stage, provided it is the right kind. The beginner will probably not buy a stand with a mechanical stage, though he might do worse things, but if he should even once perform any serious work with that

device, he will, I am sure, never abandon it voluntarily. A mechanical stage is a "thing of beauty," and if well made the rest of that hackneyed quotation is descriptive of it.

But what is it? Only a stage so made that the horizontal and the vertical motions are accomplished by rank and pinion. The description is short, it seems a small matter, but the stage is one of the most important parts of the stand. An inconvenient stage means an inconvenient stand. If properly constructed, a mechanical stage is strong, light, firm, durable, desirable, and unrelinquishable. If improperly made it may be strong, firm, thin and light; it will be altogether abominable. Scarcely any part of the stand sees so much active service as the stage, unless it is the fine adjustment, and scarcely any part must approach perfection so closely as the stage unless, again, it is the fine-adjustment mechanism. To have this part loose and wabbling, with the image dancing at every turn of the screw, is as bad as having lost motion in the racks and pinions of the mechanical stage, or to have the parts loose and rattling, or to have them "lift," that is, to be raised above the general plane surface whenever the milled heads are turned to bring the mechanism into action. Every movement should be smooth, prompt, noiseless. Every slightest touch of the milled heads should be followed by a movement of the stage-plate that shall be visible through the microscope, whatever it may be to the naked eye. To be forced to turn the milled heads through part of a revolution before the leaves of the pinion engage the teeth of the rack, is something that will undermine the best disposition the microscopist is blessed with; and to feel the pinion crunch against the rack, while the whole jolts

and bounces along, and lifts the object out of focus, will complete the ruin. Nothing of that kind is made in the United States, but something very similar is made outside of the United States.

The beginner, however, must understand that a mechanical stage, although one of the most desirable of microscopical luxuries, is by no means a necessity. Work as good, important and valuable may be done without it as with it. The convenience and accuracy of its movements, its immediate response to every touch, and the confidence that the microscopist speedily learns to have in it, are among its attractive qualities.

One great advantage in the use of the mechanical stage has not been mentioned. This is the procedure called "sweeping the field," or the act of searching every part of the object field by field, so as to examine every feature and to bring every part of a preparation under the objective. With the ordinary stage as moved by hand, it is easier to fail to bring a minute point or minute object into the field than it is to find it. The stage may carry the desired object in every direction except the right one, while with the mechanical device, the slide may be examined in every part and corner, with the certainty of finding what is sought. If one field be carefully scanned as the stage carries the slide horizontally under the lens, and the specimen be then moved forward to a distance equalling the width of the field and again swept horizontally, the desired object can scarcely fail to be finally caught.

Many practical microscopists have devised safety stages to be used with very high-power objectives, so as to prevent disaster, should the lens and the cover-glass come in contact. They seem hardly necessary for the

careful microscopist, who is usually so cautious in approximating objective and slide, that contact rarely takes place.

But probably the simplest, and therefore the best, among the many safety stages described by their inventors, is the one designed by Mr. C. Stewart and published in the "JOURNAL OF THE ROYAL MICROSCOPICAL SOCIETY" of London, for January, 1884. It is intended, as Mr. Stewart says, to provide an economical but effective arrangement for protecting slides from breakage when being exhibited under high powers to large classes of students, an intention which suggests the usefulness of the device at microscopical soirees.

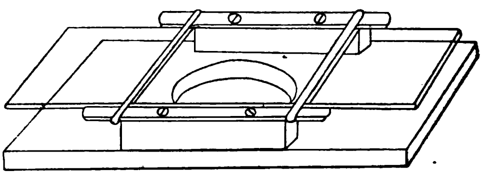


FIG. 1. Stewart's Safety Stage.

It is shown in Fig. 1. It consists of a wooden strip about as long as the glass slide and somewhat wider, with a central aperture, and two wooden side-pieces about one-quarter of an inch high. To each of the latter is fastened a thin strip of brass which projects beyond the ends of the wooden pieces. Across these projecting ends two small rubber bands are stretched, and the slide, passing between them, is delicately suspended in the air, so that at the least touch of the objective it sinks, and warns the microscopist of the danger. This effective device can be made at home by any one, even the least ingenious.

The Mirror-Bar.

Most of the smaller American instruments now-a-days have the swinging mirror-bar which on them is not objectionable, since they commonly have no provision for sub-stage apparatus, with the exception of the diaphragm which is usually attached to the lower surface of the stage. The mirror may therefore be swung above the objective for its illumination, and so fully supply the place, in this connection at least, of the bull's-eye condensing lens. In use, the mirror-bar is turned on its pivot until the mirror is above the level of the stage, when the concave mirror is manipulated until the light is thrown on the object, the parts being returned to their former position at a moment's notice. To obtain the effect of oblique light, the mirror and its bar are swung to one side below the stage as far as may be desired, and the light again arranged by altering the position of the reflector.

As a rule oblique light is used only in the study of the striæ of diatoms, and seldom for anything else. Commonly the light is made as accurately central as is possible, and here is one of the objectionable features of this otherwise convenient, swinging mirror-bar as applied to the cheaper stands. It often forces the student to work unsuspectingly with oblique light. On the best instruments a provision is made for clamping these swinging parts in any position from "dead central" to any angle of obliquity, and there is no danger of involuntarily using what is not wanted. With the advanced microscopist this danger is not great, since he can tell at a glance, whether the light is properly centred or not. With the beginner, however, it is different. His eye is not sufficiently educated to perceive whether he is proceeding correctly or not, and if

the mirror-bar has no clamping or centring adjustments, it is as likely as not to be turned aside, giving the observer undesirable shadows to look at, and to disturb the corrections of his non-adjustable objectives. On the best instruments then, these swinging parts are an admirable convenience. On "Students'" stands they may be an annoyance, unless the beginner is warned in advance, and unless the manufacturers would add some simple marks to show when the parts are truly centred, as might easily be done at no extra cost, and little extra labor.

The Mirrors and their Use.*

The Acme Lamp of J. W. Queen & Co.

When but one mirror is supplied with the stand it generally is, and always should be, concave. As a rule however, two mirrors are mounted on opposite sides of the same setting, one plane, the other concave. The size of the former does not much matter, but the latter should be as large as possible, two inches in diameter not being too small for the smallest. The surface should be silvered, the ordinary looking-glass amalgam of mercury and tin not having a power of reflection equal to that possessed by a silvered surface, and presenting a grayish appearance to the eye. The mirror-box turns so that either the plane or concave surface may be used at will, and it rotates on a stem connected directly with the bar, or by means of a jointed arm.

The proper lighting of the object, and consequently of the microscope, is one of the most important accom-

*In the preparation of this chapter the author has been greatly indebted to an anonymous paper in "Science Gossip."

plishments for the beginner to acquire, and he will learn that there is a good deal of mathematics involved in the study of the concave mirror. From the plane surface the light is reflected unchanged, that is, the rays are reflected as they are received, the angle of incidence being equal to the angle of reflection. In certain circumstances impracticable in actual practice, the plane mirror may focus the light of the sky. With this almost impossible exception, the action of the plane surface is entirely different from that of the concave mirror. When the latter receives parallel rays it reflects them so that they are forced to converge and to come to a focus, while the divergent rays are variously affected according to certain optical principles. For the mathematics of the action, and for the optical laws governing them, the reader must consult the treatises dealing with the science of optics. Yet the novice should know the best position for the lamp and for the mirrors, in order to obtain the most desirable effects.

The concave mirror need not necessarily be placed at such a distance below the stage that parallel rays will be focussed on the object, although it should be movable in a vertical direction so that that focus may be obtained if desired. It is often necessary to have something more of the effect of diffused light by lowering the mirror, thus throwing a broader and less intense illumination on the object. The beginner may know when the mirror is focussed by noticing on the slide the reflection of the window-frame by day, or of the lamp-flame at night. And since the concave microscope-mirror is always a part of the inner surface of a hollow sphere, its focal distance may be readily learned, as well as the size of the sphere of which it is a part.

To ascertain these, a simple experiment must be

made with parallel rays of light. The sun is so far from us that the rays are already practically parallel and no apparatus is needed in the experiment, but if a lamp be used, since its rays are divergent, it must be placed as far as possible from the mirror, or the light must be passed through a bull's-eye condensing lens. In either case the mirror must be placed directly opposite the source of light, the lamp-flame, if it be used, being as nearly as may be on a level with its centre; then by moving a white card back and forth between the two, seek that point at which the reflected spot is the brightest and the most distinctly defined, measure the distance from the card to the mirror, and the principal focus in inches has been obtained. This distance in every concave mirror is one-half the radius of the hollow sphere of which it is a part, so that by multiplying the focus by two the radius will be known, and by multiplying the radius by two the diameter of the sphere will be obtained. The mirror on my own stand has a principal focus of four inches, the radius of the sphere is therefore eight inches, and the diameter sixteen.

The angle at which the microscope slopes in relation to the table-top; the angle at which the mirror slopes in relation to the optic axis of the microscope; the distance of the mirror from the object, and the distance of the lamp from the mirror, affect for the better or for the worse the excellence and the desirability of the resultant illumination, every change in any of these positions or distances having its immediate effect. For every inclination of the microscope a calculation may be made, whose result will give the proper inclination of the mirror, the proper position of the lamp and of the bull's-eye condenser. The beginner, if he wish

to enter on the study of microscopical optics, will have no trouble in finding accessible books for consultation. The beginner who reads these chapters must accept the somewhat dogmatic statements without any very extended explanatory reasons.

It has been found that about the best position for the lamp and the mirror is such that the parallel rays shall form an angle of ninety degrees with the axis of the microscope, and forty-five degrees with the axis of the mirror, or that imaginary line drawn through the centre of the mirror and perpendicular to its surface, and that the flame shall be on a level with the centre of the mirror and the centre of the bull's eye condensing lens, or the plano-convex lens forming the front of the microscope-lamps supplied by the dealers. The angle which, in this case, the rays form with the axis of the instrument being ninety degrees, one-half of that, or forty-five, is the angle of incidence, and the mirror is also inclined at an angle of forty-five degrees with the axis of the microscope.

The principal focus of the mirror and the angle of incidence being known, the proper distance of the former from the object may be ascertained by applying the following rule: "Multiply the cosine (to be found in any book of mathematical tables) of the angle of incidence by the principal focal distance, and the product will be the required distance between the mirror and the object." The mirror on my own stand having a principal focus of four inches, the cosine of forty-five degrees being 0.70711, the mirror should be about two and eight-tenths inches from the object in order to converge and to focus parallel rays upon it.

But we are talking about the use of parallel rays when those from artificial light are divergent. How are

they to be made parallel? By the bull's-eye condenser, either on a separate stand, as commonly supplied with the instrument by the dealers, or on the front of the Acme or of the Stratton microscope-lamp. The property of this plano-convex lens is to change diverging into parallel rays, or parallel into convergent, so that we have only to place it between the lamp and the mirror, at the proper distance from each, and the deed is done.

When the bull's-eye lens is used to illuminate the surface of an opaque object, the question is often asked: Which side should be turned toward the light, the plane or the convex? The answer is that it depends upon the intensity of the illumination desired. The plano-convex lens of the bull's-eye has two principal foci, their distance being somewhat different according to which side is toward the lamp; with the convex surface in that position, the bright spot of light at the focal point is surrounded by a broad disk of fainter illumination, but with the plane surface toward the lamp the focal distance is increased, the light condensed at the focus is somewhat less brilliant, but the circle of fainter illumination has almost disappeared. To get rid of this weakening outer circle and to have only the bright spot, as well as to gain the convenience of the longer focus, it is better to place the plane side toward the object; but when the parallel rays are to be thrown on the concave mirror to be thence converged to a bright focus on the subject, it is better to place the convex side toward the object.

The difference in the appearance may be observed, and the distance of the two foci measured, by experimenting with a card in a way that needs no explanation. But to obtain the best results, either when using the bull's-eye with the concave mirror, or when using it as a

direct illuminator for opaque objects, the flame should always be placed on a level with the centre of the lens, and as nearly as possible at the focal point.

Unless we have a microscope-lamp like the Stratton Illuminator, or the Acme, or some other special form, it often happens that we wish to dispense with the use of the bull's-eye condenser, which is always more or less troublesome, and to take the light directly from the lamp with the concave mirror. Here the conditions are changed, the rays of light being divergent. The concave mirror will focus them, but the mathematics of the process are too abstruse to be entered into here. Still the microscopist may readily find the proper distance for the lamp from the mirror, or for the mirror from the object, to obtain the best effects, provided he will make an easy calculation, and refer to some treatise on microscopical optics for the explanations.

If it is desired to know the proper distance at which to place the mirror from the lamp, we must know the radius of the mirror (twice the principal focus), the angle of incidence and the distance of the mirror from the object. If we then multiply the radius by the cosine of the angle of incidence, and that product by the distance of the mirror from the object, and divide the result by twice the distance of the mirror from the object, minus the product of the radius by the cosine of the angle of incidence, the quotient will be the distance in inches for the lamp from the centre of the mirror. This seems complex when expressed in words, but in algebraic formula it is seen to be simple enough. Let A represent the distance in inches between the lamp and the mirror; d the distance from the mirror to the object; R the radius of the mirror, and a the angle of incidence, which in this case we will assume to be

forty-five degrees. Then the algebraic formula will be,

$$A=\frac{d\ R\ cos\ a}{2d—R\ cos\ a}$$

If the value of the symbols be *a*, 45°; *d*, 4 inches; *R*, 8 inches; we shall have

$$A=\frac{4\times8\times.707}{8—8\times.707}$$

or about nine and one fourth inches (9.23), the position of the lamp varying according to the value of the symbols.

It may be more convenient to find the proper distance for the mirror from the object, that of the lamp and the angle of incidence being known. In that case the formula will be,

$$d=\frac{A\ R\ cos\ a}{2A—R\ cos\ a}$$

Assuming the values to be; *A*, 10 inches; *R*, 8 inches; and *a*, 45°, we have

$$d=\frac{10\times8\times.707}{20—8\times.707}$$

or about four inches (3.95).

These superficial studies scarcely touch the subject of the concave mirror, and the student who desires to make a detailed examination must go elsewhere than to these chapters.

The plane mirror is used only for the illumination of very low power objectives and for certain special purposes to be referred to hereafter.

As intimated, the bull's-eye lens is usually a troublesome piece of apparatus to use successfully. It is

focussed with some difficulty, and unless correctly focussed it is almost worthless, while it often happens that after the microscopist has labored to get the awkward thing into proper position, an accidental touch disturbes it, and the careful adjustments must be repeated, with much loss of time and of patience. Yet a bull's-eye lens is essential, and the dealer often supplies one with the stand. My advice to the beginner, however, is to do without the bull's-eye in a separate mounting, as supplied, and to substitute Messrs. J. W. Queen & Co.'s Acme lamp, the Stratton Illuminator, or some similar form. In these the bull's-eye is attached to the front of the lamp, the flame being properly focussed before the plane surface, while the whole arrangement is one of the most convenient, useful and manageable devices that microscopists can have on the table, while the cost is but little more than that of a first-class bull's-eye lens.

When using a concave mirror, the lamp, under all circumstances, must be so placed that the flame is on a level with the centre of the mirror. This is an essential prerequisite to the attainment of the best results. Under all circumstances, too, the broad side of the flame must be kept away from the mirror. The only proper portion of the flame ever to be employed is the narrow edge. It may seem strange that this slender line of light, as it appears to be, should have more intense illuminating power than the whole wide front of the flame, but such is the fact, and in all microscopical investigations it is the only portion that should be used. It is said to have about eight times the intensity of the broad side.

To the reader the use of daylight or of lamp-light may seem one of personal preference only; but such is

not the fact. My belief is that the majority of working microscopists never employ daylight when they can command artificial illumination. The latter may be obtained at almost any time and is entirely manageable. It may be made into a blaze that shall almost blind the user, or it way be subdued and softened until to see it is a pleasure, its result a wonder and its effect beautiful.

The field illuminated by the soft, white, steady glow of a good microscopical lamp is not only charming, but useful; and it is beneficial to the eye, to which light is a tonic and a healthful stimulus. The image produced is the best the objective is capable of forming. It is clear, sharply defined, sparkling and satisfactory, if all the conditions are favorable. A better image may be obtained from an inferior objective and lamp-light properly employed, than from a good objective and diffused daylight in whatever way the combination may be used. On the eye the effect is not injurious even after hours of prolonged investigation, provided, of course, the light be properly modified. Only the eagle can gaze directly at the sun, and even this favorite simile of the poets forces the eagle to pose as a fraud, for the bird protects its eye by the nictitating membrane, the third eyelid, when gazing sunward. No microscopist will gaze at the unmodified light of a strong flame focussed by a concave mirror, or perhaps intensified by the sub-stage condenser, without protecting his eye by some device for reducing the blinding glare. But when such modification is made, the effect of artificial light is not harmful.

The image formed by an objective of a greater amplification than that possessed by the one-half inch or by the four-tenths, does not have by daylight that exquisite sharpness of outline and brilliancy of aspect

that it will have by artificial light. The general appearance of things is watery and washed out, if the light be taken from the blue sky, as must commonly be done, or almost destructive of the eye if taken directly from the sun. The only commendable light by day is that reflected from a white cloud, or from a plane white surface illuminated by the sun. Direct sunlight is never used except at times in photomicrography. But it is seldom that white clouds are sufficiently accommodating to place themselves before the window and to remain stationary and properly illuminated; and the plane white surface is not often at one's command, while a lamp is always ready. If the microscopist can make a plate of plaster-of-Paris, and take the light from it when illuminated by sunlight, the effect will be good, almost as good as the effect of white cloud illumination, but while the plaster-of-Paris plate in diffused daylight gives a white field, it lacks, with high powers, that soft intensity obtainable from the smallest flame properly managed. On a rainy day the microscopist would fare badly if he had no artificial light at his command, and the microscopist that can work with the instrument at night or not at all, would fare as badly if lamp-light was as harmful and worthless as some writers seem to think it is.

With daylight and no sub-stage condenser, use the concave mirror; if the stand have a sub-stage condenser then the plane mirror should be employed.

When artificial light is used, the table and the room should be only faintly illuminated; there should be no side lights to throw their reflections where they are not wanted, and no extraneous light to interfere in any way; there should be only the little spot of intense brightness in the centre of the object, if the sub-stage con-

denser be used, where it will do all that any one will want done, if it be properly managed. My advice to the beginner is to use the light of day in his microscopical work as little as possible, and only with the lowest powers, but to pay particular attention to the source of his artificial supply, and to its manipulation.

Never take the light from a gas-flame. The quality is not commendable, and the incessant flickering is pernicious in every way. Kerosene oil is the best illuminant that can be used. The circular wick of the German student-lamp gives a powerful light, but the flame of a small flat wick is much to be preferred, since its edge is intense and perfectly steady, the latter being of prime importance, as a trembling light is one of the worst things that the microscopist can use. If the beginner does not care to buy a microscopical lamp, he will find that a small hand-lamp, such as may be had for twenty-five cents, will be all that he will need, especially if he use a bull's-eye lens, or a sub-stage condenser.

The light should be as white as possible. The yellow glare of the ordinary flame as seen through the microscope is hot and acrid. It should be cool, soft and soothing. To make it so is not difficult. The older microscopists were accustomed to produce the change by filtering the light through a glass globe of water colored faintly blue by sulphate of copper (blue vitriol,) deepening the tint by the addition of strong ammonia-water, thus obtaining the so-called monochromatic light, or light of one color, often referred to in microscopical literature. The result was that the blue water excluded the yellow rays, the light being consequently cooled and softened in appearance. This, and indeed all other methods of accomplishing the same end, some-

what decreases the intensity of the illumination, but enough will be left for all purposes, and it seems to have the advantage of adding a desirable quality to the light, even when the half-inch wick is used and turned so low that the flame rises only just above the burner. The device is troublesome, but the beginner may try it by making a cell with parallel sides of glass, uniting the parts with hot Canada-balsam or by a cement made by melting together yellow wax and Canada-balsam. The cell should be about one-eighth inch deep from front to back, and filled with a saturated solution of the copper-sulphate and ammonia, the color of which should be as nearly sky-blue as possible.

As Dr. W. H. Dallinger has remarked, "True monochromatic light really almost changes an achromatic lens into an apochromatic one; but the great difficulty has been hitherto how to produce monochromatic light which should be absolutely such, and yet be within the reach of all, and under control as to its measure of intensity when employed with high powers." The ammoniated solution of copper-sulphate is not truly monochromatic, and experiments have frequently been made to find an easily prepared and easily managed solution whose effect should approach more nearly the desired result. Such a solution has been obtained by certain microscopists in Europe, and highly recommended as being practically monochromatic. I have used it to a limited extent, but have not observed that the effect is any better than with the use of the properly colored glass as a light-modifier. Perhaps with further study and experimentation the solution might produce more satisfactory results. It is used in the way already described for the copper-sulphate solution, and gives with artificial illumination an orange

light slightly tinged with green. It is made as follows:

Sulphate of copper, 2 ounces and 1½ drams;
Bichromate of potash, 1 dram and 2 scruples;
Sulphuric acid, 12 minims;
Water, 6½ ounces.

Similiar results may be attained by simpler means. If the microscopist must use day-light, it will be of better quality if he will fasten a pane of pale blue glass in the window, and receive the light through it. At night nothing more is necessary than to place one or more small pieces of glass of a deeper blue above the ocular, or in the sub-stage between the mirror and the object, or between the mirror and the light. In the latter event a blue-glass chimney is all that is needed, if a sub-stage condenser be not used.

None of these devices deprives the light of those qualities demanded in what has been called "microscopical gymnastics," or the use of first-class objectives to show the finest striations on difficult diatoms, or a series of lines closely ruled on glass plates, such as those made by the late F. A. Nobert, of Germany, and the late Charles Fasoldt, of Albany, N. Y. If the reader desires to practise microscopical gymnastics, however, he will find that the sulphate of copper or the bichromate solution will be a rather better assistant than the blue glass, since the former is said, by the late Dr. J. J. Woodward, to increase the defining power of first-class objectives when used in these gymnastic exercises, as the color may be controlled, while glass of just the right sky-blue shade is not so common as it should be. For all other purposes the glass is amply sufficient, supplying the best obtainable modification of the illumination.

The centre is an important point in the microscope. The optician takes the greatest pains to have the component lenses of his objectives most accurately centred. The maker of the stand is careful to have all movable parts act in a certain relation to the optical centre or axis of the instrument; and the working microscopist is always anxious to have the illuminating beam strictly central, except when he desires to use oblique light. The centre of the mirror is always in the optical axis of the microscope, or should be, for ordinary work. To accomplish this centralizing of the illumination Mr. Edward Pennock has suggested an admirable method, which the beginner is advised to adopt for all occasions. Mr. Pennock's instructions are substantially as follows:

Having the object in place and lighted from the mirror, the objective screwed on, and the eye-piece in the tube, first focus. Then remove the eye-piece and applying the eye centrally to the end of the body-tube, notice the spot of light at the back of the objective. It may appear as in *A*, figure 2, in which case move the mirror or diaphragm or both until the illuminating beam appears central, as in *B*. If now your lens is a good one, properly adjusted, and the inner circle of *B* presents an evenly illuminated disk, you should obtain a

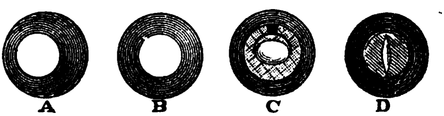


Fig. 2.—Pennock's method of centring the illumination.

good, sharply defined image. But there may not be light enough or there may be too much, in which case use a diaphragm of different size, or vary its distance from the object, thus varying the angular size of the

illuminating pencil. If the diaphragm be too large or placed too near the object, it ceases to affect the angular size of the illuminating beam, although it may act in another way, and in this case the image of the mirror is seen within the circle of the diaphragm, as at *C*, if the objective is of sufficient aperture.

If lamp-light be used, the image of the flame may be seen within the disk of the mirror and diaphragm, as at *D*. This shows that the beam is not focussed upon the object. This may be remedied by a bull's-eye condenser placed near the source of light, making parallel the rays falling on the mirror, or simply by altering the distance of the mirror from the stage. In some cases, however, the mirror is not of the right focus and the latter course cannot be adopted. The appearance should be like *B* as nearly as possible. This is as useful and successful when the sub-stage condenser is used as it is with the mirror alone.

Reflected and transmitted light are terms which are somewhat puzzling on first acquaintance, although they are often met with in microscopical literature. They refer to the illumination in connection with the object, and not, as might be supposed, to the bull's-eye condensing lens or the mirror. A transparent substance is always examined by transmitted light, the illumination being passed or transmitted through it from below, in which event the mirror may be used, or the microscope may be placed in a horizontal position and the light taken directly from the lamp flame. Opaque objects can not be studied by transmitted illumination. They are restricted to reflected light, the illuminating beams being thrown upon the surface, from which they are reflected. Most objects seen by the naked eye are seen by reflected light.

The Diaphragm.

The reader may suppose that there is but one form of microscope-diaphragm, a flat disk of metal pierced near its margin by apertures of various sizes. No idea could be more erroneous. There are so many forms that a plausible supposition is that whenever an optician has a sleepless night, instead of tossing on his bed like ordinary folks, he invents a new diaphragm. Then he publishes it and nobody ever hears of it again; certainly nobody ever uses one out of a hundred of the diaphragmatic monsters noted in the books. There are the Iris, and the Spiral, and the Cylinder, and the Calotte, and the Spherical. There are oblong plates pierced by all sorts of holes radiating in all sorts of directions. They have horizontal slits, and vertical slits, and oblique slits. They have big holes, and little holes, and pin holes, and round holes, and oblong holes, and square holes. They are concave and convex. They are fastened below the stage, to its under surface, and in a depression that brings them on a level with the upper surface. There is one form of two cylinders or rollers revolved by a milled head, and encircled by two conical grooves. They have special forms of holders. They rotate on their centre, or they may be swung aside on a movable arm attached to the stage. There are already so many that about the only kind remaining for the reader to invent is one that shall be wound up and go by clock-work and a spring, or by electricity, or steam, or water-power or wind.

It has been said that the working microscopist can get along with very few of the apparently desirable devices offered by the dealers. That is true. Few things microscopical are absolutely indispensible, and among these I should not class, for general use, these refine-

ments in the way of diaphragms. If the beginning microscopist is not careful he will be lost in a wilderness of diaphragms. Yet the device in its simplest form is essential to the proper action of the instrument, and to the proper interpretation of the magnified image of the object. Most young microscopists use too much light. They seem to think that if a little is good, much is better. The result is that the eye is exposed to risk, and the finer details of the object are drowned in a flood of glaring brightness. The field should be toned down to a soft and pleasant glow, and to accomplish this, aside from the use of the blue glass, the circular disk-diaphragm in the stage, or attached to it, is all that is needed. This should be turned until the opening which gives the proper effect is beneath the object, and no aperture should be used because it seems to be the right one. Try them in succession, and adopt the one proper to the occasion. It is said that the opening to be used should be the one which corresponds in size to that of the front lens of the objective. This is true if the diaphragm is a permanent fixture and on a level with the upper surface of the stage, but if it can be racked upward and downward, the light from the concave mirror may be modified satisfactorily by this movement. Few of the cheaper stands however, have a diaphragm thus movable, and those adapted to the use of a sub-stage condenser have the metal disk, or other form, so arranged that it may be entirely removed, and special diaphragms employed below, or sometimes above, the lenses of the condenser, although the last-mentioned position is not to be commended.

Dealers, and microscopists as well, differ in their opinion as to the proper position of the diaphragm when it is to be attached to the stage. Some place it half an

inch or more below, others nearer on a level with the upper surface. Its action differs according to its position and the character of the light. As to its position the student must usually abide by the decision of the maker, unless he select a stand with the diaphragm on the sub-stage, or one adapted to the use of a sub-stage condenser. If it is attached to the stage, it should be as close to the object as possible.

The reader will of course understand that parallel rays cannot be affected in any way by the position of the diaphragm in reference to the object. With converging rays, however, the result is different. In this case the lowering of the diaphragm will obstruct more of the oblique rays the lower it is depressed, until it comes in contact with the mirror itself. A similar effect is obtained with converging rays by diminishing the size of the aperture in a diaphragm immediately beneath the stage, the smaller the opening the greater the number of oblique rays obstructed. With parallel rays, however, the depression of the diaphragm is without noticeable effect, the amount of light being diminished by the use of decreased apertures in the diaphragm-plate, so that a diaphragm immediately below the object can be used, by changing the size of the apertures, to modify either parallel or converging rays. With the sub-stage condenser diminished illumination is obtained by depressing the condenser, the focus of the appliance thus being removed below and from the object. As only parallel rays should be used with this sub-stage accessory, their power and number are diminished by the use of diaphragms of different apertures, as well as by the differing positions of the instrument below the object, the diaphragms being below the condenser. The proper place then for the plate of dia-

phragm-openings is immediately beneath the object when the condenser is not used; when the condenser is used the diaphragm should be as close as possible to its back lens. Some stands have it attached to a cylindrical box at some distance below the stage. Such stands are good ones to be rejected.

The proper amount of light to be employed in ordidary investigations cannot be taught in words. The beginner must learn by experience, using his own best judgment. Avoid a glare, and avoid semi-darkness. There is a commendable medium, which the beginner must find for himself, if he work alone.

The Eye-Piece, or Ocular.

This part of the microscope fits loosely into the upper end of the body-tube, from which it may be readily removed. Its function is to magnify the image produced by the objective. In form it is a short tube bearing a lens or a combination of lenses at each end and varying in construction and in name almost as greatly as does the diaphragm. The negative eye-piece is the one commonly used. It is so named because its focus is within the tube, at a level with its diaphragm. It cannot be used as a magnifying glass without the objective.

Eye-pieces should properly fit the body-tube. A tightly fitting ocular, and one that is too loose, are equally annoying and inconvenient. It should not be loose enough to shake about in the tube, although this may be easily remedied by winding with paper; it should be of a size sufficient to allow it to drop in by its own weight, and out, too, if the microscope is turned upside down.

The negative eye-piece is often called the Huyghenian because the celebrated Dutch astronomer Huyghens, who died in 1695, first used one of similar construction on his telescope. Its focus, or the point at which the image is formed, falls about midway between its two lenses, while in the positive the focus is below the lower glass. In the negative eye-pieces the lenses are plano-convex and have their plane surfaces directed upward, while a diaphragm with a single central aperture is placed within the tube at a point corresponding to the place where the image is formed. This diaphragm serves to intercept all those marginal rays not active in the production of the image, and partly to correct the spherical aberration as well as the chromatic, the diaphragm being further utilized as a place of support for the eye-piece micrometer used in the measurement of microscopic objects.

The diaphragm is an important factor everywhere in the microscope, but here it is especially useful, not only because it acts as stated, but also because upon the size of the aperture in its centre depends the size of the field. By contracting that the field may be diminished in extent. The diameter of the body-tube is not altogether responsible for the size of the field, and neither is the diameter of the eye-piece itself. The diaphragm is here the important factor, the same sized opening

being used in all negative eye-pieces of the same power.

The size of the field appears larger to most persons than it really is, and this apparent size is misleading to many, whose estimates are often amusing and amazing. There is a vast difference between the apparent and the actual fields. The apparent is due to the eye-piece, while the actual is represented by the actual amount of surface shown at one time by the objective, this area varying with every magnifying power and every objective. The actual field may be measured by placing a stage micrometer below the objective and counting the number of spaces included within the circular lighted area, but to obtain the apparent diameter as produced by the eye-piece, a simple calculation is necessary.

The rule is to multiply the diameter of the diaphragm-opening by the magnifying power of the eye-lens. If the aperture is half an inch across, and the eye-lens magnifies ten times, then the field is apparently five inches in diameter. To me these matters, even so simple a one as this, are more easily manageable if put in the shape of an algebraic formula. In this instance, then, if D represent the diameter of the diaphragm-opening, P the magnifying power of the eye-lens, and F the diameter of the apparent field, we will have $F=DP$, or, in the supposed case, $F=\frac{1}{2}\times 10$, or five inches.

But the power of the eye-lens, how can that be obtained? This is one of those interesting little points about which the inquiring student soon wants to know something. The magnifying power of the eye-lens is equal to ten inches (the arbitrary standard of distance for distinct vision), divided by its focal length in inches, so that it only remains to obtain that focal length, and

both problems are solved. The formula here would be $P=\frac{10}{F}$, the focal distance of the eye-lens being obtained in the manner described for ascertaining that of the bull's-eye condenser or of the pocket-lens, except that here the convex surface must always be turned toward the light, since that is its position in the ocular. In one of my own oculars measured while writing this, the focal distance of the eye-lens is $\frac{14}{10}$ inches which, by the formula $P=\frac{10}{F}$, gives $P=10\div\frac{14}{10}$, or $7\frac{1}{7}$. The diameter of the diaphragm-opening is by actual measurement 0.7 inch. By the first-mentioned formula, $F=DP$, we have $F=7\frac{1}{7}\times.7$, or five inches, the apparent diameter of the field, which is correct, as I have proved by another, simpler, and on that account, probably a better way.

This is to make the measurement by means of the camera lucida, the latter being applied to the eye-piece and the microscope placed in a horizontal position with the camera lucida ten inches from the table, if the Wollaston form of camera be used, the limits of the field being marked by pencil and then measured by the ordinary foot-rule.

If the reader make the experiment by measuring the focal length of the eye-lens, he should take special care to focus the lens as accurately as possible, since the difference of a small fraction of an inch makes an astonishing difference in the result.

The size of the actual field varies with the nominal focus and with the power of the objective. The field of Zeiss's variable *A** when at its lowest power is, by actual measurement, thirty twenty-fifths of an inch, (1.2 in.), and, according to the approximate estimates of Mr. Edward Bausch, a power of twenty-five diameters will show a surface about one-fifth inch wide; fifty di-

ameters will include an area one-tenth of an inch in width; one hundred diameters, one-twentieth inch; five hundred diameters, one one-hundredth, while one thousand diameters will exhibit a space only one two-hundredths of an inch wide.

At present eye-pieces of different powers are named after the letters of the alphabet, the lowest magnifying power being *A*, the next highest *B*, and so on down the alphabet, the power increasing as the letters approach *Z* and ampersand. This method might not be objectionable if it conveyed a correct idea of the power, as it does not, some makers producing *A* eye-pieces that magnify as the *B* of other opticians, no two dealers having precisely the same standard. As a rule, however, the *A* ocular roughly approaches two inches in focal length, with a power of five, and so continuing through *D*, *E*, *F* and others with a focal length of $\frac{2}{3}$, $\frac{1}{2}$, $\frac{4}{10}$, $\frac{1}{8}$, $\frac{1}{4}$ inches, with powers varying from fifteen, twenty, twenty-five to thirty, forty or more diameters.

A better plan would be to mark each with its focal length, two inches, one inch, or whatever it may be, and to have it understood that a certain length always represents a certain invariable power. Thus the one inch should possess a power of ten diameters; the two inch of five; the one-half by twenty; the one-fifth by fifty. And if not only the focal length could be stamped on the cap of the eye lens, but the power as well, the change would be acceptable and the advantages great. Eye-pieces are made varying in focal length from two inches to one-sixteenth inch. The power of the last should be one hundred and sixty diameters. With it is I do not know, and do not care to know, if that knowledge must be contingent upon personal ownership, for I would not accept such an ocular

as a gift, if I were to be forced to use it. A more worthless cumberer of the apparatus box I cannot imagine. No human eye could see anything satisfactorily with such an eye-piece.

The reader may desire to know how to measure the power of his oculars and thus learn what the *A*, *B* and *C*, or the 2½ or 1 inch represent in amplification. For this purpose the late W. H. Bulloch, of Chicago, has devised a simple apparatus usable by anyone, and has described an easy method whose results are at least approximately correct. The apparatus is shown in figure 3. It consists of the microscope *B* supplied with a two-inch objective, and placed in a horizontal position opposite to the tube *G D* which carries at *E F* the eye-piece to be measured, while at the end *D* is a diaphragm pierced by an oblong opening of known size, as at *H*. *C* is a stationary stage bearing a micrometer ruled to one hundredths of an inch or to tenths of a millimetre. In Mr. Bulloch's instrument the parts are all brass and fitted with rack and pinion adjustments, which are very well in their way, but not essential to the working microscopist, who can make the tube *G D* of stiff paper, and fasten it to the top of a pile of books as the writer has done, using the microscope for the other part of the instrument, the diaphragm at *D* being also of paper, while the stage *C* is that of the microscope. The distance from the di-

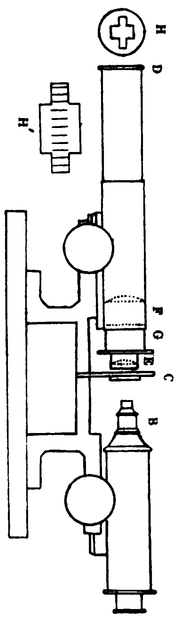


Fig. 3. Bulloch's Apparatus for Measuring the Power of Eye-pieces.

aphragm D to the diaphragm within the eye-piece to be measured should be ten inches, the arbitrary standard of length for distinct vision.

Screw to the microscope the two-inch objective, as it is the most convenient for this purpose, and focus it on the lines of the micrometer at C. Then bring the tube $G\ D$ toward the micrometer until the image of the aperture at H is focussed on the same lines, presenting the appearance of H' in the figure. Count the number of spaces occupied by the image, and divide the number into the known size of the aperture in the diaphragm at H. In Mr. Bulloch's case the diaphragm-opening was 6.5 millimetres, which covered eleven spaces of a micrometer ruled to tenths of a millimetre. A simple formula and its application is, P the power to be obtained; D the size of the diaphragm opening, and m the number of micrometer spaces occupied; then $P = \frac{D}{m}$. In this case the value of D is 6.5 mm.; of m eleven-tenths mm, and the calculation, in the form of a decimal fraction, is $\frac{6}{1}:\frac{5}{1} = \frac{65}{11}$ or about six. The reader of course understands that when his micrometer is ruled in parts of an inch, the diaphragm opening at D in the figure, may be of any convenient size provided it also is in parts of an inch. In the case of one of Mr. Bulloch's eye-pieces belonging to my own stand, and measured very hastily while waiting for the dinner-bell to ring, being done, therefore, under very adverse circumstances, the result was 4.4+, the power marked on the cap of the eye lens being 4.5. With greater care in reading the micrometer the result might have been actually that of Mr. Bulloch although the difference is very slight. The tube $G\ D$ was a pasteboard cylinder into which the eye-piece to be measured was wedged with a corner of the

pocket handkerchief. The micrometer was ruled in hundredths of an inch, and the diaphragm aperture was two-tenths of an inch long (*D*), occupying four and one half micrometer spaces (*m*). The calculation was, $P=\frac{D}{m}$ or $\frac{200}{45}$, or 4.4+.

However careful of his stand the microscopist may be, the dust will collect on it and especially on the eye lens. This when abundant is indistinctly visible and should be removed. There is one right way to do this, and that is not by a careless wipe with the pocket handkerchief, as I have seen done. A particle of grit may be on the glass or in the cloth, when a scratch will be made that may be disastrous in its effects. To avoid such danger, blow away the dust with several short quick puffs of the breath, then carefully wipe the surface with the Japanese filter paper, as originally recommended by Prof. S. H. Gage, of Cornell University. This paper is extensively used by the dentists, and may be had cheaply from dealers in dental supplies. It is soft and thin, with no tendency to collect the dust, and with no kaolin or gritty matter in its substance. It may therefore be used almost recklessly. Prof. Gage has also recommended it for cleaning the fronts of objectives, for which purpose it can not be excelled. A sheet of it should be cut into small squares and kept in a covered box on the microscopist's table, a piece being used once only, to be thrown away after each application to the objective or ocular.

It is sometimes difficult to describe a special object in the field, or some special part of an object so that another person may recognize it. This is particularly difficult if the other person has had no experience in the use of the microscope. He will be as likely to gaze with awe at an air bubble or a bit of colored

wool, as at the specified object. To obviate this, a pointer called an indicator is occasionally used. As originally devised by Quekett it consists of a fine steel hand so pivoted within the eye-piece, and near the diaphragm, as to be in the focus of the eye lens, and capable of being swung forward to the centre of the field so as to point to the special object, and then swung back out of sight when not in service. It is not much used now, but an anonymous writer describes a simple form made by attaching a hair to the diaphragm so as to extend half way across the field. He gums the piece of hair to a bit of paper, the end projecting to the proper distance beyond the edge. When dry he cuts the paper to the right size, moistens the gummed side, and attaches the whole to the diaphragm. He says that "This simple arrangement is entirely satisfactory, and we have it now in constant use. The hair is not objectionable in the ocular, as it appears as a fine sharp line, and is quite overlooked when one gets accustomed to its presence." To me personally the presence of the fine line would be an annoyance. However, if the microscope is much used for showing objects to others, so simple an arrangement might be commendable.

The Micrometer.

The micrometer is an instrument for the measuring of minute objects or of short spaces. In some form it is in frequent use by the microscopist. It consists of a series of fine lines ruled on glass, the distance between the lines varying according to the wish of the microscopist, or of the optician that makes the plate. These bands of rulings are prepared by special and complicated machines, some of which are so delicate and so easily influenced for the worst, that they are allowed to work only in the darkness and the stillness of the night. Nobert, of Prussia, was for many years the most noted maker of fine rulings, some of his work having for a long time served as tests for the best and highest-power objectives. In this country we have had three microscopists who have turned their attention to the making of fine micrometers and bands of closely ruled lines, Prof. W. A. Rogers, who did splendid work but who has now retired from this field and transferred his ruling-machine to Prof. M. D. Ewell of Chicago, the other worker of note in this department being the late Charles Fasoldt of Albany, N. Y., whose extravagant claims in regard to his rulings detract from the estimation in which he otherwise would have been held by intelligent microscopists. His assertion that he had ruled a band containing one million lines to the inch is known by every well-informed microscopist to be an absurdity and impossibility. No human eye has seen more than 120,000 ruled lines to the inch, and no human eye probably ever will. Professor M. D. Ewell is at present the only person in this country ruling fine micrometers, and all his work is commendable, while his prices are exceedingly reasonable.

The microscopist should possess two forms of micro-

meter, one for the stage, the other for use in the eye-piece, where it is always employed without the stage-micrometer, after the value of its spaces have been ascertained. This is a great convenience over the old and awkward, and often impossible, method of using the stage-micrometer by placing the object above it and focussing down through the thickness of both to see how the lines stood in relation to the margins of the specimen. This was oftener than not impossible for use with high-power objectives, which always have a short working-distance.

The two kinds of micrometers differ in form as well as in position. That for the stage is mounted on a slip of glass of the standard size, while that for the ocular is a circular disk of thin glass made to rest on the diaphragm of the eye-piece tube.

The Stage-Mi rometer.

The stage-micrometer is sometimes ruled directly on the glass slip and used without a cover-glass; sometimes it is ruled on the cover itself which is then mounted on the slip, the first-mentioned kind probably being rather more easily used. The lines in either case are usually filled with graphite to make them more distinct, for it has happened that although the micros-

copist has known that the lines were there, they have been so faintly ruled that they were invisible even under the best objectives manipulated by an expert microscopist.

Usually the lines will be in two narrow bands ruled at the rate of one hundred and one thousand to the inch. These are sufficient for most purposes; yet it will be convenient for use with high-powers to have a third band ruled at the rate of two thousand to the inch, and this will not add much to the cost. If the reader should prefer to have all his measurements made in millimetres there will be no objection to it, but in that case the micrometer may well be ruled to tenths and hundredths of a millimetre. When ordering the stage-micrometer therefore, it is well to give instructions on these points, otherwise the maker will use his own judgment. For practical work nothing will be needed less than the one two-thousandth of an inch or the hundredth of a millimetre.

The stage-micrometer is rarely used for the direct measurement of the object in the way already referred to; the reasons for this have also been given. But when this can be done with very low-power objectives, the object is laid across the micrometer lines, and measured much as a two-foot rule would measure it. Thus, if the object extends across just two and one-half of the one-hundredth inch spaces, it of course measures two and one-half hundredths, or $\frac{1}{40}$ of an inch.

When the object extends into a space without entirely crossing it to the next line, the portion of the space occupied must be estimated by the eye, and here enters a source of error against which the microscopist must guard. The same holds true in the use of the eye-piece micrometer when the object extends beyond

a line but not entirely across a space. The more expert the microscopist is in estimating distances, the more nearly free from error will his measurements be in such instances. At other times, if the micrometer be correctly ruled, there will be little trouble in reading the spaces, especially since every fifth line is, or should be, longer than the remaining four, its end extending above the general level of the others. This catches the eye and enables the microscopist to read the lines rapidly in groups of five. This direct method of measuring, however, has been almost entirely superseded, that by means of the camera lucida being more accurate and better adapted to high-powers, if the microscopist have no eye-piece micrometer.

By the camera lucida process just mentioned the micrometer lines are focussed, after the microscope has been placed in a horizontal position, with the eye-piece about ten inches from the table-top. The camera lucida is then attached and the lines drawn on the paper upon the table. The micrometer is now to be removed, the object substituted, and the number of spaces its image occupies on the paper scale at once read. Thus, if the one-thousandth inch spaces have been sketched, and the image of the object, drawn with the microscope in the same position and with the same objective, occupies eight of those spaces, it of course measures eight one-thousandths of an inch, or $\frac{1}{125}$. A scale should be made for every objective and eye-piece, so that the image may be projected on the proper one by the camera lucida, without the trouble of drawing the micrometer lines every time this method is used. But at best this is an awkward way of accomplishing what may be done with great ease and rapidity with the eye-piece micrometer.

Efforts have been made to induce microscopists to adopt some standard to which micrometers shall be ruled, so that all measurements may be expressed in the same terms. In this country and in England, parts of an inch are used, unless the microscopist orders otherwise; on the continent of Europe parts of a millimetre. The American Society of Microscopists and others have endeavored to induce microscopists to adopt the one one-thousandth of a millimetre, or about one-twenty-five thousandth of an inch as the standard for measurements, but thus far without much success, although it will probably become common in time. This one one-thousandth of a millimetre is to be known as the micron, and to be represented by the Greek letter μ. In Europe it is frequently used, but in this country writers in the scientific periodicals have not employed it generally enough to make the majority of readers of microscopical literature familiar with it. As a unit of distance, the measure is in every way commendable, and should be used whenever possible.

The Eye-piece Micrometer.

This, as its name indicates, is used only in the eye-piece, where it is placed on the diaphragm. It is made to fit in the tube, or in an adapter which then rests on the diaphragm. It is used by rotating the eye-piece

until the lines lie across the object to be measured and at right angles to its length or breadth. The spaces occupied are counted, and a simple calculation gives the length or the breadth, when the value of each space is known.

To ascertain this value, a stage micrometer is needed, and when the latter has been used for this purpose it is of no further importance unless the owner should desire to ascertain the value of the spaces in another eye-piece micrometer. The stage-plate may then be put away, as the eye-piece disk is now all that will be needed for all microscopical measurements.

Put the stage-plate in position and focus the lines. Remove this eye-piece, insert the one that carries the eye-piece micrometer, and again focus. The stage-micrometer is then to be moved until one of its lines exactly coincides with one of the lines in the eye-piece micrometer, and as nearly as possible in the centre of the field. Notice how many spaces in the eye-piece are needed to fill one space of the stage-plate, and obtain the value of one of the intervals in the former, by dividing the value of the single space on the stage-micrometer by the number of spaces it fills in the eye-piece micrometer. Thus, if one of the one-hundredth inch intervals on the stage-plate is just filled by three spaces on the eye-piece micrometer, the value of one space of the latter will be $\frac{1}{300}$ of an inch, or the $\frac{1}{100}$ of the stage-plate divided by the three divisions occupied in the eye-piece micrometer. Or if ten spaces in the eye-piece fill one of the $\frac{1}{1000}$ inch divisions on the stage-micrometer, then the value of the one eye-piece space is $\frac{1}{10000}$ inch, or $\frac{1}{1000}$ divided by ten, and any object that just fills one such space in the eye-piece would be $\frac{1}{10000}$ inch in length; if it occupied five spaces

it would be $\frac{5}{10000}$ or $\frac{1}{2000}$ inch long. The value of the spaces must be ascertained in this way with every objective, and the measurement of the object should always be made under the same conditions as far as regards tube-length and the position of the adjustment-collar of the objective, any change in either at once altering the value of the micrometer-spaces.

It sometimes happens that a certain number of divisions in the eye-piece cannot be made to fill exactly a certain number on the stage-micrometer, a fraction of a space being left over. For instance, thirteen divisions in the eye-piece may perhaps occupy two and one-half of the one one-hundredth inch spaces on the stage-plate. To simplify the calculation in such a case, the draw-tube may be extended until a certain number of eye-piece spaces will exactly fill a certain number on the stage-micrometer, when the position of the tube must be recorded, and all subsequent measurements made with it at that place. Or, if the microscopist have an eye sensitive to small distances, he may estimate the part of a space occupied.

The position of the adjustment-collar of the objective also alters the value of the spaces, since any movement towards closed point or bringing the component lenses closer together, increases the magnifying power, and decreases it when made toward open point. With adjustable objectives, therefore, the value must be ascertained for every position of the collar, unless the microscopist is willing to place the adjustment-ring at open or at closed, and to allow it always to remain there when measurements are to be made.

The eye-piece also affects the value of the spaces, since they are magnified by the eye-lens whose power, of course, varies in oculars of different focal lengths

It is best, indeed, always to employ the same ocular, allowing the micrometer to remain on the diaphragm, using that eye-piece for measuring-work only. The one-inch, or the one and one-half inch ocular is a desirable one for the purpose.

The value of the spaces with each objective should be recorded for ready reference. The reader will probably prefer to devise his own method of doing this, but the following is the writer's tabular form, given only to show the manner of preparing the record in this particular instance.

Value of Micrometer Divisions with each Objective.

Objective.	Adjustment.	Inch (fractions.)	Inch (decimals.)	Micron μ	D-tube.
1-10	Closed.	1-6000	0.0001666+	4	In.

The number of intervals on the eye-piece micrometer is of no importance, provided they are equally spaced. The ruling may therefore be safely left to the maker. The late Dr. J. J. Woodward, however, thought otherwise, for he has said that, "So long as the English microscopists continue to express the results of their measurements in decimals of an English inch, there will be American microscopists who will do the same,

either for all purposes or for particular work, and of course it is very desirable that the measurements also should be accurate. The stage-micrometers on this system in the market are usually ruled in hundredths and thousandths of an inch. The latter divisions are too wide to give values to the eye-piece micrometer with the higher powers, while the five-thousandths and ten-thousandths and even finer divisions ruled also on some of these micrometers, are inconveniently close. I would advise the makers to rule such micrometers four-tenths of an inch long, divided into hundredths of an inch, one of the hundredths being divided into ten, another into twenty-five. These latter spaces, each representing one twenty-five-hundredth of an inch, sufficiently approximate the hundredth of a millimetre to be used with equal convenience with the higher powers. The scale on the glass eye-piece micrometer, used with these stage-micrometers, should be, if specially made for the purpose, four-tenths of an inch long, divided into one-hundred parts, each one two-hundred-and-fiftieth of an inch; but these divisions would so closely approximate those of the metric eye-piece micrometer proposed, that it might be used without inconvenience instead."

To Ascertain the Comparative Enlargement of a Drawing.

It is sometimes desirable to learn how much the drawing exceeds the size of the object, especially when drawings are to be made to a certain scale. To do this, divide the length of the drawing by the actual length of the object as ascertained by the micrometer, and the quotient will be the enlargement of the sketch. Thus, if the drawing is five-tenths of an inch long, and the object one one-hundredth of an inch, the sketch is enlarged fifty diameters.

How to Care for the Instrument.

When the microscope is received from the dealer it will be in a case, with a lock and key which are often mentioned in the catalogues as if they were rare and unfamiliar things. After the box has been lifted to the table by the brass handle at the top, the door is opened and the owner glances within, his heart beating a little faster, and agreeable anticipations bringing a pleasing expression to his face. The instrument will probably have the front toward the back of the case, therefore turned away from the microscopist. At first acquaintance it will turn its back on him in more senses than one.

I have seen men clutch the upright stand by the body and the milled heads of the coarse adjustment, drag out the unresisting thing and set it down on the table with a bang. Such men are not fit to possess a microscope. The instrument may be strong and well made, but as some one has said, it is never necessary to brutalize it. If it be supplied with a base-board as it should be, gently slide it out of the case by pulling board and all toward you, and as gently place it on the table. If it be not attached in any way to the case, carefully lift it out by means of the arm. If you treat the instrument kindly it will repay you a thousand fold. If you attempt to coerce it, a rebellion will be speedy and your downfall sure.

Sometimes one eye-piece will be found in the body tube, sometimes in a side box or drawer, according to the size and style of the case and the stand. In any event the eye-piece is to be gently dropped into the top of the body-tube as the stand rests vertically on the table. The microscopist seats himself on a chair and in any position that he may find comfortable. Every observer will form habits of his own in reference to his position before the instrument, and will have his own ideas as to the proper size and style of his work-table, and perhaps even to the number of legs that the table should have. Some writers have advised that there shall be three legs to the microscopical table so that it may be steady on an uneven surface. There is no objection to three legs, if the microscopist wants them. He may also sit on a three-legged stool, if he should desire to do so. But since the floors of modern houses are seldom uneven enough to disturb the equanimity of a quadrupedal table, that seems to be the preferable form, the great desiderata being firmness and solidity.

I remember that the ladies in my family were once attacked by the æsthetic notion that if I could be induced to put the microscope on what they called a "Tea-poy" table, and under a glass shade, it would look well. The table had four filamentous legs, and a shelf half way between the floor and the top, the whole being a silly invention of some frivolous mind. The thing trembled at a touch, the shelf scraped my shins, the microscope danced, the lamp wabbled, and the deluded victim expressed his opinion. Æsthetics are well enough, but they should be looked for in the object under the lens rather than in the table. I now use a strong, substantial, four-legged pine table that cost less than three dollars, and I would not change it for a Louis XIV. or for a Chippendale. All that is needed is that it shall be solid and firm, with an abundance of top space, and a drawer or two to hold the many "traps" and "dodges" that soon accumulate.

Seated before the stand, incline it at a convenient angle, the stage, the mirror, that is, the front of the microscope, of course being turned from you. When inclining the instrument, do so if possible by means of the arm; at any rate do nothing to bring a strain on the coarse or on the fine adjustment. All the least costly stands will remain in an inclined position, held there by the friction within the joint at the top of the pillar; in first-class instruments the trunnions carry tightening or binding screws, so that the wear that sooner or later becomes noticeable in the former can be taken up in the latter.

With the eye-piece in place, and the body inclined, attach the objective. To do this, rack up the body until there is no danger that the front of the lens will come in contact with the stage. Unscrew the top of

the brass box containing the objective and tip the latter out into the palm of the left-hand, supporting it with the fingers. Take it up with the right-hand, and turning the screw end upward, screw it to the lower end of the body-tube. It is unnecessary to caution the reader in regard to crossing the threads of the screws. If that be done and the objective wedged into the nose-piece, the owner of that stand may have a sad experience. Mr. Wm. Wales relates an instance of this kind where the objective could not be removed by hand, so the wise owner used a heavy pair of gas-fitter's pliers, and succeeded in damaging the instrument to the amount of forty-five dollars, pulling out the entire fine-adjustment, which in this case was on the lower end of the body. It is often useful to rotate the objective backward for a short distance, until the threads are felt to slip into place, when the lens may then be screwed home by gentle forward turns. If it does not move easily and smoothly, something is wrong, and no force should be applied, but the objective must be removed and the difficulty discovered and corrected.

If the microscope is to be used by day-light a position near a north window is the best, as the light from the northern sky is the most uniform. A white cloud illuminated by the sun is the most desirable light by day, but it can seldom be obtained. Most microscopists have some favorite position before the window, many preferring the stand so arranged that the mirror shall face the window and the sky; others place it so that the window shall be at the side of the instrument. This is entirely a personal preference, nothing, so far as I know, being gained or lost in either position. If, however, daylight is used with a sub-stage condenser, the plane mirror should be turned toward the sky. If

no sub-stage condenser is employed, then the concave surface may be directed upward.

The use of lamp-light has already been referred to, and the employment of some special form of microscope-lamp recommended. Its position in relation to the mirror may, if desired, be ascertained by the formulæ given in a preceding chapter, but I think that most microscopists, for ordinary work, do not enter into the niceties of such an arrangement, reserving these refinements for some very special and delicate investigations. The reader will find however, that any attention paid to these points, even for every-day observations, will result in good. Usually the lamp is placed somewhat in advance of the microscope, and always on the left-hand side. This gives plenty of room on the table, so that the lamp is in no danger of being overturned.

Do not handle the mirror too daintily; if well mounted there is little danger of injuring it, and a firm grasp makes it more easily manageable. At first there will probably be some difficulty in illuminating the field as it should be illuminated, but a little practice will accomplish it. The entire circular space called the field should be evenly lighted; there should be no shadows nor faintness in the glow near the edge. Some writers recommend that a piece of tissue paper should be placed over the stage-opening and the mirror manipulated until the light is thrown exactly in its centre; it is then removed and the light of course passes through the objective and up the body-tube. This is a good plan if the reader has trouble in seeing where the reflection is thrown, but usually the light may be observed on the front of the objective. The field can scarcely be illuminated while the eye is at the eye-piece; the illumination may then be completed, but not begun.

The only plan is to use the paper on the stage, or to observe when the front lens receives the light. Then apply the eye and gently manipulate the mirror, trying to improve matters; but even now the best can not be obtained. This must wait until the slide is on the stage, when the body is carefully racked down and the focus obtained as previously directed. It is possible that the field may then be evenly illuminated, but too faintly to show the object properly, or oblique shadows may be thrown across it, or only one little space at the side may be bright while all the rest is semi-obscure. This must be remedied by gently moving the mirror while eye is at the ocular. When all the circular region is lighted as well as seems possible, remove the eye-piece and centre the illuminating beam by the method suggested by Mr. Edward Pennock and described on a preceding page. Then with the eye-piece again in position, the field should appear brightly lighted in every part. It will probably be too bright, and the observer must either rack down the condenser, if he uses one, until the desirable softness of illumination is obtained, or the same result is to be worked for by rotating the diaphragm.

With very low-power objectives where the actual field is comparatively large, the apparent field cannot be evenly lighted by either mirror. With all low powers, and without a sub-stage condenser to modify the intensity, it is better to use the plane mirror. This will sufficiently illuminate the field of all below the one inch, until we reach those very low powers now used, such as Zeiss's variable A* which may be used as a three or a five inch, with all intermediate amplifications, by simply turning an adjustment collar. The field of these lenses cannot be lighted throughout its whole ex-

tent by either mirror. The concave gives only a central bright spot while the plane surface does little better. To light this large region fully, the plane mirror should be covered with a disk of white card-board, and parallel rays thrown on it by the bull's-eye condensing lens. The mirror and the card are then manipulated as the mirror alone should be. Or a more successful result may perhaps be attained by taking the light with the mirror from the brightly illuminated inner surface of a white lamp-shade. With the two-inch or the one-inch the plane mirror alone is sufficient. All higher powers demand the use of the concave surface, unless the bull's-eye lens is placed between the lamp and the mirror, with a sub-stage condenser between the mirror and the object; or unless some form of microscopical lamp is used with a permanent bull's-eye lens, in which cases the plane surface should be turned toward the condenser.

It sometimes happens that if the microscope has travelled for some distance by railroad, the owner will have trouble to get rid of a broad, crescentic shadow in an otherwise well-lighted field. No manipulation of the diaphragm or other sub-stage appliance serves to remove the annoyance; it remains partly eclipsing the field by its region of darkness, and the beginner may think that something serious has happened., The trouble is caused by the jarring of the diaphragm in the body or in the draw-tube, the journey having shaken it too far downward. Remove the body, first of course taking off the objective and the eye-piece, and push the diaphragm up a little way, repeating the operation if not at first successful.

It is well for the observer to keep both eyes open when using the microscope, and if he begin with this

plan he will be doing well, for it is somewhat of a trouble at the start to see anything in the microscope with both eyes open, as the unemployed organ seems to dominate. At first the images of the object on the table and of the object under the microscope will mingle, but as combination is impossible, the result will be amusing and annoying. At one moment the magnified image will have the mastery, at the next the microscopic objects will dominate the view, and at times the eye will fail to take cognizance of anything. But with a little practice the result is entirely satisfactory, and the brain will finally take notice of the magnified image only.

It has been suggested that instead of allowing the unoccupied eye to roam about aimlessly as it does, and as may be noticed when another person is at the microscope with both eyes open, it would be better to give it a dark surface to gaze at, or as some recommend, a white surface. Consequently many forms of eye-shades have been devised. They are all applied to or near the eye-piece, a projecting arm carrying a disk for the protection of the unoccupied eye. Dr. L. B. Hall, of Philadelphia, has described a device for this purpose which may be made by the microscopist himself.

It consists of a small, opaque disk supported by a wire extending from its outer edge downward to a point on the body-tube low enough to be out of the way of the nose, then bent upward parallel to the tube, but not touching it, and attached to a ring near the top. Dr. Hall's own eye-shade was made of No. 18 brass wire about twenty inches long, with a loop about one and three-quarter inches in diameter made at one end and covered with black paper to form the disk. The other end of the wire was made into a ring to fit the

body-tube, and the intermediate portion bent as described. The ring about the body-tube may be covered with chamois-skin if desired, to protect the lacquer.

To return the microscope to the case demands movements the reverse of those used to take it out. The body is racked up, the objective unscrewed (taking care not to drop it or to strike it against any hard substance), then gently replaced in its brass box and the lid screwed on. The slide is taken from the stage, and if permanently mounted, is returned to its proper cabinet; the mirror is turned at right-angles to the optic axis of the instrument; the eye-piece is removed and deposited in the receptacle prepared for it; the body is racked down, and placed in a vertical position, and the stand is lifted into the case, where it remains with its front looking at the back wall of the box. The door is then closed and locked. If there are children around that cannot be controlled, the key would better be carried in the owner's pocket. Two minutes' brutal usage will do more injury to a good stand than months of proper treatment. No one but the microscopist should ever touch the objectives, and he should carefully avoid the contact of his fingers with the lens. Optical glass is soft and easily injured. The owner would do well to act accordingly, for a scratched or broken objective is a ruined one.

Dust is an insidious and dangerous enemy to the microscope. It gets into the bearings and the movable parts, and harms them. The microscopist should therefore often wipe the stand with a soft old handkerchief or a fine chamois-skin. The latter is the better, since the fibres from the handkerchief often become a source of trouble. No liquid should be used; alcohol

should especially be avoided as it will remove the lacquer. The rack and the pinion-bearings may be occasionally and sparingly touched with the porpoise-oil used by jewellers, or with very superior sewing-machine-oil. Exceeding small quantities must be used, and the parts at once wiped almost dry, otherwise the oily surfaces will collect the dust, and the last state of that microscope will be worse than the first. The dealers use soft and thick grease for lubricating purposes, or a refined tallow. The parts of a well-made stand need lubricating only at very long intervals. They will work well if kept perfectly clean and free from dust.

The microscopist will sometimes be annoyed by one or more indefinite specks or spots apparently in the field, but whether on the eye-piece or on the objective he cannot decide. That they are not on the object or on the cover-glass is determined by moving the slide; if the specks remain stationary they are either on the ocular or on the objective. To discriminate between these, rotate the ocular; if the offending particles move they are on it; if not, they are on the objective. If on the former, the two lenses may be unscrewed and carefully wiped by the Japanese filter-paper; if upon the objective, the front lens may be guardedly touched with the Japanese paper, or the back combination very cautiously swept with a soft camel's-hair brush. This must be carefully done, and the brush must be scrupulously clean, otherwise the glass may be scratched. In all these operations the breath is a useful and harmless assistant.

There are often found on a slide three objects that perplex the beginner. These are air-bubbles, oil-drops and that quivering and apparent dancing of minute

particles called the Brownian movement, or pedesis, or sometimes the pedetic motion. Air-bubbles have been described as wonderful things. I remember to have once shown a slide of urinary deposit to a physician, who immediately cried out that the patient must be in a dreadful condition, for those big, round, black-bordered things surely must be deadly. Like the majority of persons unaccustomed to microscopical investigation, he had gazed at the most prominent object in the field, and not at what I wanted him to see, for he had looked at two or three air-bubbles, that are of a truth rather frightful to the uninitiated. In such cases an indicator in the eye-piece is a useful contrivance.

Air-Bubbles and Oil-Bubbles. The Brownian Movement.

Rather than take up space by an attempted description of air-bubbles, I recommend the reader, if he be not already familiar with them, to follow the plan suggested by Prof. S. H. Gage in his "Notes on Microscopical Methods," and make bubbles for examination.

Air-bubbles and oil-drops both appear with a bright central spot and a broad dark border. To obtain the former, Prof. Gage suggests that a drop of mucilage shall be placed on a glass slip and beaten with a broad blade until it looks milky on account of the inclusion

of air. Put on a cover glass but do not press it down. With this under the objective, focus upward and downward, noticing that in focussing up, the central bright spot becomes very clear and the black ring very sharply defined, until the whole is dimmed by being far beyond the focus. As Prof. Gage also says, the air-bubble is one of the most useful means for ascertaining whether or not the illumination is strictly central; if it is not, the bright spot will not be in the centre of the bubble, as it will be if the light is strictly axial. And if the mirror be swung to one side so as to make the illumination oblique, the bright spot will appear on the side of the bubble *away from* the mirror. This is an important experiment to make whenever in doubt in this connection, as precisely the opposite effect obtains in the oil-drop, the bright spot, when oblique light is used, then being on the *same* side with the mirror. Oil-drops may be prepared for examination by beating together a drop of mucilage and one of clove oil. An air-bubble has been described as a cancer-cell, and as the microbe of la grippe.

The reader may have more trouble in experimenting with oblique light than with central. About all that I can tell him is to swing the mirror to one side, usually toward the right-hand as being more convenient, and then to manipulate it until the light is properly reflected on the object, the degree of obliquity of course varying with the position of mirror-bar, the mirror or both. Frey in his work entitled "The Microscope and Microscopical Technology," says that "Considerable practice is requisite with oblique illumination. The aperture of the stage must be freed from diaphragms, or any other apparatus that may be under the stage, and the various positions of the mirror are to be tried

while the eye is looking into the microscope. Truly diabolical illumination is thus sometimes obtained, which, however, shows many fine details in an astonishing manner." Oblique light, as previously remarked, is chiefly used in the resolution of the fine lines on the surfaces of diatoms, these little ridges not being too minute to cast a shadow on the side opposite to that from which the light is received. Oblique light is occasionally used to produce delicate shadows when the microscopist is studying other objects, yet the effect is rarely employed. In such cases however, when the mirror is swung far to one side, and the objective is not properly corrected, the result is as Dr. Frey calls it, truly diabolical.

The Brownian movement, or pedesis, is that continuous quivering or dancing common to all minute particles when suspended in water. It is not an evidence of life, and should not be mistaken, as it is apt to be mistaken by the beginner, for minute living creatures. It may be seen to good advantage by rubbing up a little gamboge or India ink in water, allowing the larger parts to settle, and then examining a drop of the supernatant liquid with a high-power objective. The field will be full of dancing and trembling particles, moving irregularly, but as if endowed with life. Similar movements are beautifully visible within certain desmids and algæ, especially if they are not in a healthy condition, the minute black granules there hovering together, swinging and quivering like a swarm of microscopic bees. It is also noticeable within the little sacs near the base of the spinal nerves of the common frog, and in almost any place where finely divided matters are in suspension in a thin liquid. The cause of the movement is not known. It has been supposed to be pro-

duced by currents of heat or of electricity, but the subject is still without a satisfactory explanation. How long it lasts is also unknown. One writer claims to have prepared a slide which he examined at the end of seven years, and found the particles as active as at first. Soap and water are said to produce an energetic pedesis, and it is claimed that our hands are cleansed as effectually by the violent Brownian movements of the soap, as by its chemical action. In any event, do not mistake this uncertain dancing, as seen under the microscope, for the quivering of minute bacteria or for any other living plants or animals.

In addition to the three foregoing microscopical bugbears, which cease to terrify when well known, the student should make himself familiar with the appearances of starch-granules, and with cotton, woolen and linen fibres, especially when colored, as woolen fibres are likely to be if the work-room is carpeted, as it should not be. I can scarcely imagine an object any more astonishing on first acquaintance than a purple fibre from the carpet or elsewhere. These, with cotten and linen, are likely to be found in any preparation; even in mounted slides they are common, having fallen into the mounting medium or been entangled in the object itself. The student may mistake them for something more important, unless he makes himself familiar with them at the beginning of his studies. Cotton fibres have been mistaken for casts from the uriniferous tubules of the human kidney.

The difference in the appearance of convex and concave bodies is also important and useful. Microscopical and ordinary vision differ so widely from each other, that it is often impossible to decide whether a surface is convex or concave, especially if the object be

uniformly covered with markings that may be bosses or depressions; sometimes the same trouble is experienced by the naked eye. Grooves belong in the same category with depressions. When the objective is racked upward, a convex surface will appear lighter; a concavity will appear lighter when the objective is focussed downward.

It is often difficult to find a small object and bring it into the field. This is especially true with high powers, the trouble increasing with the increase of magnification, because the actual field of high-power objectives is so small that the chances of escape for the small object are much greater than are the microscopist's for capturing it, especially if the mechanical stage be not used. The only recourse is to remove the high-power objective, substitute a lower power, find the object, place it in the centre of the field, and then to re-attach the high-power lens, when the object sought should be somewhere within the illuminated space.

Thin Glass.

Before thin glass was obtainable as easily and cheaply as at present, microscopists used very thin pieces of mica, and for use with exceedingly high-power object-

ives whose working-distance is excessively short, it is to a certain extent still used. The older microscopists preserved their objects between two pieces of window-glass.

The method of manufacturing this thin microscopical glass is a secret known only, I believe, to the Messrs. Chance of Birmingham, England. Some time ago the report passed the rounds of the journals to the effect that the method of making it had been discovered in Germany, and that it would soon be supplied very cheaply, but nothing further has been heard from it of late. All that is used in this country is imported in sheets and cut by the dealers into circles or squares of various sizes. A suggestive remark in this connection is made by Dr. S. Czapski when writing of the peculiar cover-glass needed for use with Zeiss's latest apochromatic objective of 1.63 N. A. He says, "The production of these cover-glasses in the usual way —by blowing in a furnace—was forbidden by their substance." Further than this the method of manufacture has not been explained.

The thin sheets of glass, so brittle that they break almost at a word or a look, are cut with a diamond. The circles are made by placing on the glass a plate pierced with holes somewhat larger than the disks desired, and a diamond is then run around inside these openings until the entire surface of the glass sheet is covered with the scratched circles. To attempt to break these out would be followed by disastrous consequences, but if the glass be laid aside for a day or two, the disks will fall out of their own accord. The squares are cut with a diamond and a ruler, after the thin sheet has been attached by water to a flat surface, usually of plate glass. After the cutting the squares are easily

broken off by sliding the sheet to the edge of the support.

When the glass comes from the dealer it is never clean enough to be used for microscopical purposes, but to clean it sufficiently nothing more is usually needed than a careful wiping between two surfaces of soft, old muslin. I have never found it necessary to use any of the chemical mixtures recommended by some authors.

Several mechanical cleaning-devices have been described, but nothing is better than two smooth, wooden blocks, each with a surface tightly and smoothly covered with soft, thick chamois-skin. The cover-glass is placed on one block while the other rubs the surface until it is clean, when the whole is turned over and the other block rubs the other side of the glass. With this simple contrivance it is hardly possible to break the thinnest cover.

After being cleaned the glass should be kept clean, as well as free from scratches. It is exposed to the latter if thrown loosely into a box, where a particle of hard dust may do mischief.

Mr. C. E. Hanaman of Troy, N. Y., has described a method of keeping the covers protected from accident and from dirt. He places them in drawers or in boxes filled with narrow strips of new white blotting-paper, between which they are stood on edge. This method, Mr. Hanaman says, not only preserves them from breakage and enables him readily to pick them out when wanted for use, but also assists him to select, for special preparations, those of the most desirable thickness, as, by holding the drawer or the box between the eye and the light, it is easy to select the thickest or the thinnest.

The glass varies a good deal in thickness even in the

same lot as supplied by the optician. Its thickness may be most conveniently measured by some sort of micrometer-gauge, of which there are several in the market for the use of machinists. Carl Zeiss makes one especially for the microscopists, but either of the three manufactured in this country, especially that of Bausch and Lomb, will answer equally well. It is not only convenient but important to have covers of different thicknesses sorted out, so that almost any kind may be had at a moment's notice, and the micrometer-gauge is slightly more accurate in its results than the fine-adjustment screw, with which the thickness may also be estimated. An experiment made while writing this gives the thickness of a cover as measured by a gauge to be one two-hundredth inch, while the fine-adjustment screw gives 0.0045, or about $\frac{1}{223}$ inch.

To use the former, place the cover between the jaws of the instrument, close them and read the thickness in hundredths and thousandths of an inch. To use the fine-adjustment screw for the purpose, if the milled head be graduated and the value of the spaces known, it is only necessary to count the number of divisions employed in focussing from one surface of the glass to the other. A few particles of dust will answer as objects on which to focus, or a minute drop of ink on each side of the cover, and so close as to be together in the field of a high-power objective, but not close enough to overtop each other. In the experiment referred to, the number of the divisions on the milled head used in focussing from the lower to the upper surface of the cover, were four and one-half, and as each division corresponds to a movement of the body-tube of one one-thousandth inch, the cover was four and one-half thousandths, or $\frac{1}{223}$ inch thick.

The most desirable as well as the cheapest and best micrometer-gauge now in the market is made by Messrs. Bausch and Lomb of Rochester, N. Y. This instrument possesses several commendable features which may become of great importance to the working microscopist.

If the reader have no graduated milled-head to his fine-adjustment screw, and no micrometer-gauge in his possession, he may still measure his thin glass, although the process is not as convenient as with these appliances.

Place the cover upright on the stage so that its edge shall present toward the objective. A narrow slit in a cork or even in a slide of soft wood will hold it in position, and enough light will be reflected from the edge of the glass to supply the demand. Focus the objective on the glass, place the microscope in a horizontal position, apply the camera lucida to the eye-piece, and draw two lines to represent the borders of the magnified edge of the thin cover. Remove the glass, for it substituting a stage-micrometer, and draw one or more of the micrometer spaces on the paper. As the value of these spaces will be known, a comparison between them and the magnified width of the glass may be easily made, the two having been enlarged to the same degree by the same objective and eye-piece. If the width of the glass as represented on the paper occupies one-fifth of the micrometer-space as shown on the paper, the actual thickness of the glass will of course be one-fifth of whatever may be the value of that special space on the micrometer. If the distance for the glass should equal the distance of the one one-hundredth inch space on the micrometer, of course the thickness of the glass is one one-hundredth of an inch.

Dr. S. Czapski reports the following original method for determining the thickness of the cover-glass over mounted preparations, a measurement which it is often important to know for high-power work. The procedure presupposes the possession of some cover-glasses, the thickness of which is known, and that the head of the fine-adjustment screw is divided by radial lines.

The upper and lower surfaces of the cover are focussed with central illumination, and the amount of turn given to the fine-adjustment screw noted for each cover-glass, it being unimportant whether the exact value of the screw is known or not; the reader therefore having it in his power to make his own radial lines on a disk of paper to be pasted on the milled head of the fine-adjustment screw. If the surfaces of the cover-glass do not present any obvious marks to focus on, an artificial one, such as dust or scratches, must be supplied. If the numbers thus obtained be compared with the known real thickness of the covers, a reduction-factor is obtained from their quotients, which is available for determining measurements of a similar kind, that is to say, for measurements of other cover-glasses with the same objective, ocular, diaphragm and tube-length. The focussing differences are always to be multiplied by this factor in order to obtain the true thickness of the layer.

As an example:—Objective DD Zeiss, diaphragm 8 mm. in diameter; tube length 155 mm.; and four cover-glasses, the thickness of which, already ascertained, are 0.146, 0.168, 0.187, 0.22. The focussing differences marked by the head of the fine-adjustment screw were 35, 40, 45, 52 divisions. Then the reduction-factors in $1/1000\mu$ are $\frac{146}{35} = 4.17$; $\frac{168}{40} = 4.20$; $\frac{187}{45} = 4.16$; $\frac{220}{52} = 4.23$; or on the average 4.19, say 4.20. If the thick-

ness of these cover-glasses had not been known, but the focussing difference had been obtained and multiplied by 4.2, the results would have been 0.147, 0.168, 0.189, 0.218, instead of 0.146, 0.168, 0.187, 0.22. Differences of + 0.001, 0.0, + 0.002, — 0.002; a result more than sufficiently accurate for the purpose.

Another method of measuring the cover-glass of a permanently mounted preparation by means of the adjustment-collar of the objective, has been suggested by Professor C. K. Wead. This also necessitates the possession of a cover whose thickness is accurately known. With the adjustment-collar placed at zero (the open point), dust, finger-marks or other minute objects are focussed on the lower surface of the cover-glass whose thickness is known, and the collar is turned until similar objects are in focus on the upper surface. This should be repeated several times and a record kept of the number of spaces through which the collar has been turned; take the average number of spaces and divide it into the known thickness of the cover. The quotient will be the number which should be used as a multiplier of the spaces on the collar when it is used in the foregoing way to ascertain the thickness of a cover-glass on a mounted slide.

An example will make this plain. Suppose the known thickness to be 0.0058 inch and several readings of the collar to be $3^{\circ}.6$, $3^{\circ}.75$, &c., the average of all the experiments being 3.56. Dividing 3.56 into 0.0058 (the known thickness of the cover used to obtain the value of the spaces on this special objective), the quotient is 0.001629, which is hereafter to be used as the multiplier of the spaces utilized over some cover of unknown thickness. If we assume, for the sake of the example, that the number of spaces is 7.50, multiplying this by

the decimal fraction mentioned, we have 0.0124175, the thickness sought for the cover of the mount.

This convenient method may be verified by the graduated milled-head of the fine-adjustment screw.

It is exceedingly important to know the thickness of the cover when using non-adjustable objectives. These lenses are corrected by their makers for a certain thickness, and as the adjustment cannot be changed, and since the microscopist, until recently, has not known for what cover-thickness the objectives were intended, he was at the mercy of circumstances, and forced to accept and be content with whatever image he could get. Now we are able to use covers of at least approximate correctness with our non-adjustable objectives, thanks to Prof. S. H. Gage, of Cornell University, who has investigated the matter. Prof. Gage submitted certain questions in relation to the subject to the various opticians of the world, and from his published results I take the following, so that the reader, if he possess non-adjustable objectives by any of these makers, may use covers of the proper thickness to obtain the best results, provided his microscope body-tube is of the standard length.

$\frac{25}{100}$ mm.	J. Grunow, New York. H. R. Spencer and Smith, Buffalo, N. Y. Powell & Lealand, London.
$\frac{16-25}{100}$ mm.	Ross & Co., London.
$\frac{16}{100}$ mm.	Bausch & Lomb, Rochester, N. Y.
$\frac{15-20}{100}$ mm.	Carl Zeiss, Jena.
$\frac{16}{100}$ mm.	Zeiss for his Apochromatic oil immersions.
$\frac{15}{100}$ mm.	The Gundlach Optical Co., Rochester, N.Y. R. & J. Beck, London.
$\frac{12-17}{100}$ mm.	J. Zentmayer, Philadelphia.
$\frac{10-12\frac{1}{2}}{100}$ mm.	Nachet et Fils, Paris.

$\frac{10}{100}$ mm. Swift & Son, London.
$\frac{15-18}{100}$ mm. C. Reichert, Vienna.

The glass, which is said to be crown-glass, from which the covers are made, is brittle, and until the microscopist becomes somewhat of an expert he will break them with amazing facility. The skill needed in handling the fragile things is easily acquired, but reasoning from the number of devices recommended for the purpose, their inventors have despaired of acquiring that skill themselves, and have judged others by their own standard. Many and peculiar cover-glass forceps are obtainable, all more or less useful, perhaps, but I have never tried them, having always relied on my fingers alone. The simplest device, and one readily made by any novice, is the following, recommended by Mr. J. C. Douglas, who says that he long wanted "a simple appliance for picking covers out of the liquid in which they may be soaking, selecting them from their box, placing them flat upon the object to be examined or mounted, and picking them off the slide when necessary after examining the object covered. Forceps and needles have grave inconveniences. Chase's mounting forceps simply drop the cover, and are inferior, both in simplicity and utility, to the following plan: Cut a piece of suitable size from a flat rubber ring; fix this, by a large-headed pin cut short, on to the end of a cedar stick, driving the head of the pin so as to form a depression in the rubber; wet the rubber, and on pressing it against a cover-glass it will adhere to it, and the glass may be manipulated as desired. To disconnect the rubber from the glass, it is merely necessary to incline the stick so as to detach the rubber at one edge, when the adhesion ceases at once. The apparatus is more durable if a little cementing material be used on

the stick, as the pin sometimes draws through the rubber."

Personally I prefer to get along without any other help than a fine needle in a match handle, using the needle to lift the cover so as to take it in the fingers, and also as a means to lower it slowly over the object after having placed one edge against the slide, supporting the opposite margin by the needle. In this way the cover may be gradually depressed or as slowly raised.

The Objective.

The objective is the combination of lenses applied to the lower end of the body-tube, and so named because, when in use, it is near the object to be examined. It produces an enlarged image of the object, which is in its turn enlarged by the eye-piece, the optical combination thus forming the compound microscope.

When the optician has, with infinite labor, accurately ground the minute bits of glass which he is forced to use in his high-power objectives, when he has carefully placed them in the brass mounting so that the centre of each lens shall be precisely over the centre of all the other lenses below it, and when he has corrected, as well as he may, the chromatic and the spherical aberrations, he finds that the cover-glass which the microscopist places over his objects, is the cause of further trouble.

Correcting the Objective for the Cover-glass.

An objective that will produce a fine image of the object without a cover-glass, that is, one corrected for an uncovered object, will give an imperfect image when used over covered specimens. This effect was first noticed by Andrew Ross, one of the older British opticians, who also discovered the means of correcting it, this being done by separating or approximating the front lens and the back systems of lenses which together form the objective. The possession of this means for cover-glass correction makes the difference between an adjustable and a non-adjustable objective. To the former the optician adds a rotating collar, by the movement of which the microscopist alters the position of the front lens, or of the back systems, and thereby adjusts the objective for the thickness of the cover. The non-adjustable objectives are without the rotating collar or other means for altering the fixed position of the lenses, and these forms are therefore corrected by the maker for a certain thickness of cover, and are immovably adjusted at that point, so that the use of a thinner or of a thicker glass interferes with the corrections and produces an imperfect image. The thickness for which certain opticians adjust these kinds of objectives has already been given, as ascertained by Prof. S. H. Gage, and to that list the reader is referred, so that with his non-adjustable objectives he may use the cover-glass of the thickness recommended by the manufacturer.

Low-power objectives, such as the one-inch and lower, never have means of correcting them for the influence the cover-glass, and such high-powers as the one-fourth and the one-fifth are often without it, especially if the angular aperture is small. The best

high-power objectives always have the correction adjustment, the collar in the cheaper forms moving the front lens, whilst in first-class objectives it acts on the back systems, the front lens being stationary. The effect is the same in either case, but the last-mentioned method is the better, since it obviates all danger of bringing the front lens in contact with the cover, to the probable detriment of one or of both, and, which is as important, prevents the possibility of throwing the lenses out of centre as may sometimes through rarely happen when the adjustment is made by the front lens.

In most adjustable objectives the collar is so graduated that when the adjustment has been obtained for a certain cover-thickness it may be recorded, and repeated in the future without loss of time. When the collar is at zero the lenses are as wide apart as possible, and the adjustment is said to be open, or at the open point, and it is then corrected for an uncovered object. When turned as far as possible in the opposite direction the lenses are brought nearer together and are then said to be closed, and the objective is corrected for the thickest glass over which it can be used. Some cheap British objectives are adjustable by the sliding back and forth of an outer tube carrying the front lens, two marks on the brass mounting being labelled "covered" and "uncovered." But this method is very inelegant, uncertain and inaccurate.

The influence of the cover is scarcely noticeable even with moderately high powers of small or of medium angles of aperture. With wide angles it becomes a disturbing element of importance, at least to the accomplished microscopist. By the novice the effect would probably be overlooked even when using the best of wide-angled objectives, yet like so many other points

in use of the microscope, as one's knowledge increases and as the eye becomes educated and drilled in the performance of optical feats new to it at first, the observer will begin to perceive deficiences in the image, especially if he read of the fine action of similar objectives in the hands of others, or sees that action through the microscope of his expert friends.

The microscopist must teach himself by experiment and by study how to adjust his objective. He will often go wrong if he be working alone, for the proper results can be recognized only after much experience. How best to make the adjustment must be worked out by the solitary student slowly and painfully; it can be taught by personal intercourse and demonstration; it cannot be taught on paper. The last mentioned method has been tried, and the failure was a dismal one. Yet there are certain suggestions which are valuable and helpful, and may be used as crutches until the novice is able to walk alone. If all opticians would graduate the adjustment-collar, as some now do, so that the proper thickness of cover-glass should be indicated by the figures on the brass mounting, the difficulty would be lessened, as we could then measure our thin glass and adjust accordingly.

The image should be clear, distinct and brilliant. It should not be misty, semi-obscure or dull. The margins, as some one has said, should be as sharply defined as are the finest lines in the best steel-engravings, and the narrow boundary lines should be the narrowest possible and perfectly black. These appearances depend greatly on a quality of the objective called its power of definition, and for this the optician is responsible. But in reference to these delicately defined outlines a writer has said, that when a good objective is correctly ad-

justed, they should be about $\frac{1}{100000}$ of an inch in width.

Every movement of the adjustment-collar necessitates a change in the focus, so that while adjusting the objective the microscopist keeps one hand at the fine-adjustment screw, and the other on the milled ring of the collar, following the movement of the latter by a counteracting movement of the fine adjustment, the collar, at the beginning of the work, usually being placed at zero, the open point of the lenses. The objective is then focussed, and the collar turned toward the closed point until the best definition is obtained, the microscopist altering the position of the adjustment toward open and closed even after he has what seems to be a good result, so that he may improve it if possible.

There are two suggestions in this connection that are exceedingly useful to the novice and to the amateur. The one is made by Mr. W. H. Wenham, and is that the microscopist shall select any dark speck or any opaque portion of the object, and bring the outlines into perfect focus; then place the finger on the fine-adjustment screw and move it briskly backwards and forwards in both directions from the first position. Observe the expansion of the dark outlines of the object, both when within the focus, that is, when the object is nearest to the objective, and when it is without the focus, or furthest from the objective. If the greater expansion, or "coma," is when the object is without the focus, the lenses must be placed further asunder, or toward the mark "uncovered," that is, toward the open point or zero. If the greater expansion is when the object is within the focus, the lenses must be brought closer together, or toward closed point. When the objective is in proper adjustment, the expansion of the

outline is exactly the same, both within and without the focus. When the scales of the insect called the *Podura*, and also when diatoms are used as the test objects, if the dots or other markings on the surface have a tendency to run into lines when the object is placed without the focus, the lenses must be brought closer together; but on the contrary, if the lines appear when the object is within the focus, the lenses should be further separated.

This is an exceedingly difficult method in actual practice, demanding much experience and more skill than is possessed by even accomplished amateurs. The novice will soon observe that for his purposes the suggestion is worthless. Yet is a valuable method, and in the hands of an expert microscopist, capable of satisfactory results. Still, even for the expert, there is a better method, that of adjusting for the best image, and it is doubtful if the accomplished microscopist ever thinks of using any other.

Another, and for the beginner, much simpler method is that recommended, I think, by Dr. Lionel S. Beale. Here, with the adjustment-collar at zero, the objective is focussed on the object, and the collar turned until a particle of dust, a striation, or any minute inperfection on the upper surface of the cover is brought sharply into focus, when the objective will be corrected for that particular glass and preparation. The microscopist then re-focusses with the fine-adjustment screw, and proceeds with the investigation. This however, is applicable only to objectives whose adjustment-collar moves the front lens.

The *Podura* already referred to, and whose scales are so useful to the microscopist for testing certain qualities of his objectives, is an agile little insect to be found

under stones and sometimes in damp cellars, where it jumps about with surprising alacrity. Its scales should be mounted dry, but it is much the better plan to buy a slide of them from the dealer, since the little creature is difficult to capture, and is in addition, not very common.

The scales are minute and have given the opticians and the microscopists a lively time in the discussion as to the character of the markings which the microscope reveals. These markings have the form of exclamation points from which the dot or period at the base has been removed. The discussion, which is even now unsettled, is whether the exclamation points are spines projecting from the surface of the scale and from which they may be removed by electricity, as some contend, or whether they are simply elevated folds or ridges of that surface. But whatever may be their character, they form excellent objects over which to study the adjustment of the objective. When the objective is properly adjusted and focussed, for the focussing is here of great importance, the exclamation marks should stand out, each one distinct from its neighbor on each side, and the lower part should not trail off into the head of the mark below it, but should end clearly and sharply, with a well-defined space of varying extent between its termination and the rounded head or upper region of the next exclamation point below it.

Messrs. R. and J. Beck, of London, issue a circular descriptive of their "National Stand," in which the appearances of the *Podura* scale are shown under the correct and incorrect adjustments of the objective, within the proper focus and without it. These are here reproduced in Figs. 4–9. In Fig. 4. the scale is shown as it appears when the objective is correctly adjusted

Fig. 4.

Fig. 5.

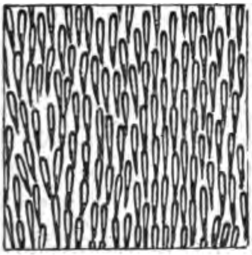


Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Podura Scale.

Fig. 4, as the scale should appear, the objective being correctly adjusted and focussed. Fig. 5, the same as it appears on each side of the focus, when the objective is correctly adjusted. Fig. 6, here the adjustment is correct, but the focus is slightly wrong. Fig. 7, the objective is incorrectly adjusted, but properly focussed. Fig. 8, the same beyond the focus. Fig. 9, the same within the focus.

and focussed; in Fig. 5 as it appears on each side of the proper focus; in Fig. 6 the adjustment is correct, but the focus is slightly altered one way or the other, the change being as little as possible. In Fig. 7 the objective is incorrectly adjusted, but properly focussed, while Fig. 8 is the same as seen beyond the focus, and Fig. 9 the same when too near the objective, or within the focus.

The late Dr. Allen Y. Moore, writing about cover-correction says: Every objective has a certain color with which it shows best, and there is probably no object better adapted to the purpose of determining this color than the *Podura* scale. By examining the scale with a first-class one-fourth or higher power of medium or of wide aperture, it will be seen that the "exclamation marks" are more or less colored. Pay no attention to this at first, but carefully turn the collar back and forth until the marks appear sharpest and smallest. That will be the point of best correction, and now the color of the markings should be noticed. Having carefully determined the exact tint of best correction, throw the objective a little out of proper adjustment by turning the collar toward open point, or zero. This over-corrects it and at the same time a change in the color is noticeable. The markings seem to expand, becoming hazy. Now turn the collar towards closed until the point of best correction is passed; here the same thing is seen in regard to expansion and haziness, but a different tint seems to make its appearance. By attending very closely to this color (which is the secondary spectrum), the proper correction can easily be made. A certain one-fifteenth inch objective when correctly adjusted, shows the markings of a brilliant ruby-red (and most of the finest objectives which I

have seen show best with this color); by turning the collar toward zero they become greenish, while, if turned toward closed, they become pink. Hence, at the first trial of any such object, should it appear green the collar must be turned toward closed until the ruby tint appears, and if too pale a red or pink, the collar should be turned toward zero. By a little practice the microscopist can tell at a glance which way to turn the collar.

When using this plan the reader must remember that all objectives do not correct in the same color. What the special tint may be, the microscopist must ascertain by noting the color of the markings on the scales when the objective is at the point of best correction; he may thereafter correct the lens by means of its color (its secondary spectrum) for other thicknesses of the cover. To do this however, demands an eye very sensitive to color and to slight changes in tint.

Mr. Edward Bausch, in his little book on "The Manipulation of the Microscope," prefers the diatom called *Pleurosigma angulatum* as an object over which to make cover-correction. He recommends that the objective be placed at the open point as usual, and focussed on the diatom. If no lines are to be seen, turn the collar, and focus above and below the plane of the diatom so that this shall be indistinct, and look for the lines. Possibly, after a little, they will begin to appear faintly; if not, continue to turn the collar toward the closed point. The lines must now soon begin to make their appearance, and when they do so, they will probably seem to be above the plane of the diatom. This shows that the objective is approaching its correction for the cover. Keep the lines in focus while the collar is being gradually turned, until they and the outlines of the diatom lie in one plane, when the objective will be cor-

rected for that cover. Record the number, and since at the beginning the adjustment was at the open point, now close it, and again adjust by turning the collar the other way. The graduations should be at the same degree in both cases, or at least within two degrees of each other. If there is a greater discrepancy, Mr. Bausch states that it is due to a want of the faculty of perception; the microscopist's eye not yet having been sufficiently trained. The reader must remember however, that the proper objective is to be used with the *Pleurosigma*, or with any other test-object. With this special diatom a good one-fourth or one-fifth inch or higher-power lens will be needed. To attempt to resolve the lines with a one-inch objective would be absurd.

The striæ are more difficult to see if the diatoms are mounted in Canada balsam. When dry under the cover, they may appear almost conspicuous, and their markings be easily observed with the appropriate objective, while if the same specimens be mounted in balsam, they seem to fade away, and must be carefully sought for with a low-power objective before a high-power can be used for the resolving of the lines, or for experimenting with the adjustment-collar. Before I had used the microscope much, and when I was groping about alone and without help except my own awkward failures, I received as a present a slide of *Pleurosigma angulatum* with a cracked cover-glass. The diatoms were exquisitely clean and beautiful, but I thought to improve the appearance of the slide by applying a new cover, which I did with Canada balsam, the mount being originally a dry one. When I looked for those diatoms with their sides curved into the line of beauty, they had disappeared, and in my ignorance I threw

away the slide, thinking that the diatoms had fallen off and been lost. I have often wished for it since, for I now know that it was a valuable thing.

An objective may be adjusted for the cover by means of the draw-tube. The effect of lengthening or of shortening the tube is not so noticeable with low powers as with high, yet the same result may be attained with it as with the adjustment-collar, but to use this method the body-tube must be divided. Shortening the draw-tube in this case has the same effect as closing the lens-systems, the objective then being corrected for thicker covers, while by lengthening the tube it is corrected for thinner glass, or the systems are in effect opened. Mr. Edward Pennock has called attention to this fact, stating that objectives of high-power (¼ inch and upward), may thus be used with a different length of tube from that for which they are corrected, by using a thicker or a thinner cover-glass. For example, to use an objective on a long tube when it has been corrected for a short tube, use a thinner cover-glass. But to use an objective on a short tube when it has been corrected for a long tube, use a thicker cover-glass. To use with a thinner cover an objective corrected for a certain thickness of cover-glass, lengthen the tube of the microscope. To use with a thicker cover an objective that has been corrected for a certain thickness of cover-glass, shorten the tube of the microscope.

All non-adjustable objectives are corrected by their manufacturers for a certain definite length of body-tube, and any change in that length results in an injurious change in the adjustments and consequently in the perfect action of the lens. What that special length might be microscopists have had

no means of knowing until recently, when Prof. S. H. Gage of Cornell University, placed them under renewed obligations by ascertaining and publishing the various lengths employed by the prominent opticians of the world. To learn these Prof. Gage sent the diagram, Fig. 10, to the opticians, asking them to give him the length for which they correct their objectives, and to indicate the points between which the measurements are made.

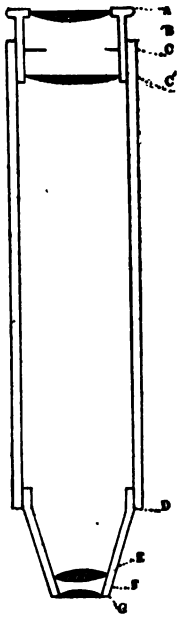


Fig. 10. Tube-length used by various opticians.

Some measure from the top of the eye-piece, to the lower end of the body, which has been suggested as a standard, since it is readily ascertained by anyone, and having the length once determined, says Prof. Gage, it would not need to be changed when an objective of different length of setting was used. Others measure from the top of the eye-piece to the front of the front lens of the objective. The following is the table of lengths as given by Prof. Gage, with references to the diagram so that the points and the distances may be seen at a glance.

Pts. included in Tube-lengths. See Diagram Fig. 10.		Tube-length in Millimetres.
a-d	Grunow, New York	203 mm.
	Nachet et Fils, Paris,	146 or 200 mm.
	Powell and Lealand, London.	254 mm.
	C. Reichert, Vienna	160 to 180 mm.
b-d	Bausch & Lomb Op. Co., Rochester,	216 mm.
	Bézu, Hausser et Cie., Paris	220 mm.
	Klönne und Müller, Berlin	160-180 or 254 mm.
	W. & H. Siebert, Wetzlar	190 mm.
	Swift & Son, London	228½ mm.
	C. Zeiss, Jena	160 or 250 mm.
a-g	Gundlach Optical Co., Rochester,	254 mm.
c-d	Ross & Co., London,	254 mm.
c-e	R. &. J. Beck, London.	254 mm.
c-g	H. R. Spencer & Co., Geneva, N.Y.,	254 mm.
c-e	E. Leitz, Wetzlar	125-180 mm.
	Oil immersions	160 mm.

Some objectives have the collar so marked and arranged by the optician that by it alone, without examining the image, the adjustment for cover may be made, provided the thickness of the cover-glass be known. If the cover is, for instance, 0.15 mm. thick, the collar should be placed at 15; if the cover is 0.25 mm., set the collar at 25. This method has been adopted in this country by Messrs. Bausch & Lomb, and by Carl Reichert and others in Europe.

Chromatic Aberration.

With the exception of Zeiss's apochromatic objectives none is perfectly corrected for chromatic and for spherical aberration. There is in all a remnant of color and a remnant of spherical trouble which it is impossible to dispose of, except by using Prof. Abbe's apochromatic devices. In what is called the chromatic or the color-aberration of the objective, the different colored rays are not all brought to the same focus, and in his efforts to remedy these defects the optician does either too much or too little. When the violet rays are focussed before the red, the objectives is said to be under-corrected; when the red light is focussed before the violet, the lens is over corrected.

Mr. Edward Bausch, the optician, in his little work on "The Manipulation of the Microscope," says that the amount of color depends somewhat upon the power of the eye-piece, becoming more conspicuous as the power is increased, and that the color outside of the secondary spectrum is not always prejudicial. The microscopist must depend upon the optician for the excellence of these corrections, and the optician will serve him well, but it is always interesting, and often useful, to be able to test the perfection of the maker's results. So far as chromatic aberration is concerned this may be done in several ways.

If an organic object is to be employed as a test, the most useful are the *Podura* scale and a diatom. Mr. Edward Pennock has published a convenient table of color corrections which I quote as follows:

Table of Color Corrections.

	Within the focus.	Without the focus.
Under correction, . . .	Brick red .	Greenish blue.
Slightly under, but a large number of the finest lenses have this color, ...	Claret . .	Light green.
Nearly colorless, shows the secondary spectrum	Lilac . .	Paler green.
Over correction, . . .	Blue . .	Yellow.

To make the appearances conspicuous the mirror should be swung to one side and the colored fringes (the complimentary colors of the secondary spectrum), at the margins of the object be noticed, and the object should, as in Mr. Pennock's table, be examined both within and without the focus, the first mentioned method by central illumination being the best for the learned optician whose eye has been acutely trained to observe slight chromatic variations. When the object is viewed under oblique light from the mirror swung toward the right-hand side, the left-hand margin of the object will be bordered with violet, and the right-hand side by yellow if the objective is over corrected; when under-corrected the left-hand margin will be yellow and the opposite edges blue or violet, a low-power eye-piece being used.

When an inorganic substance is used as the test, almost any small object or bit of dirt will answer the purpose, and in every instance that object should be as nearly as possible in the centre of the field.

Professors Naegeli and Schwendener however, recommend as the simplest and most trustworthy mode of testing the chromatic aberration, that one-half

the surface of either the front or of the back lens of the objective be covered with tin-foil or with black paper, so that only one-half shall remain optically effective. If a minute aperture in a blackened plate then be examined, it will appear colorless if the objective is perfectly achromatic, as no ordinary objective can be; or the margins will be colored as described in the foregoing experiments with oblique light. It is better, however, not to meddle much with the glass surfaces of the objective. And this method has also some other objectionable features.

With high-powers these methods are sufficient, but with low-powers the opticians recommend the use of a minute globule of mercury intensely illuminated by reflected light. This is the artificial star so often referred to in microscopical literature. It is made by beating with a broad blade a globule of mercury until it is as fine as dust. These minute globules are then used as reflecting surfaces, and are preferably mounted on a slip of black glass, as recommended by Mr. W. H. Wenham.

If the objective is well corrected the colored fringes will be pale green when the globule is without the focus, and pale violet when it is within. If the lens is under-corrected, the green will become bluish or violet, and when within the focus the color may be bright red. If over-corrected, the colors are yellow and blue, when without and within the focus respectively.

Spherical Aberration.

Of the two troubles, chromatic and spherical aberration, the latter is the more important to be entirely overcome; yet, except in the Zeiss apochromatics there is, even in the best objectives, some of it left, to which the same expressions of under and over-correction are applied. When the central rays meet before the peripheral ones, the objective is said to be over-corrected; when the peripheral rays meet first, the lens is under-corrected.

In the combination pocket-lens the spherical as well as the chromatic aberration is partly corrected by a diaphragm which obstructs the passage of the peripheral rays. For this reason the object appears more distinct, but the size of the field and the amount of light are much reduced. In some objectives this plan is adopted when the corrections are not made by the component lenses themselves, with much the same effect as in the case of the combination pocket-lens.

As a test for spherical aberration the optician makes use of the artificial star. This is done by examining it within and without the focus, and studying the coma, or the expansions of the margins. If the expansion is greater when the distance between the objective and the star is increased, the objective is under-corrected; if the expansion is greater when the reverse obtains, the objective is over-corrected.

A more accessible test for the general reader is that made by coating a slip of glass with a thick layer of India ink, which will crack into minute fissures when dry, or in which a fine needle-point may make delicate marks for the transmission of light. In using this and all other tests for the same purpose, with low-powers, the diaphragm must be removed and the mirror be brought

nearer, so that the cone of rays shall fill the whole aperture of the objective; and with high-powers a substage condenser should be used for the same purpose. The objective is sharply focussed on the edges of the fissures, and if these appear with a blue fog the aberration is not sufficiently corrected. They should be seen without a halo, clearly and distinctly. If the foggy appearance increases within the focus, the objective is over-corrected; when it increases without the focus the lens is under-corrected.

For testing both forms of aberration, Prof. Abbe has devised a test-plate consisting of a series of cover-glasses ranging in thickness from 0.09 mm. to 0.24 mm., their lower surfaces being coated with a silver film through which are ruled groups of lines varying in distance from $\frac{1}{250}$ to $\frac{1}{1250}$ inch. These covers are cemented to the slip by Canada balsam. To examine an objective of large aperture, the inventor says in his instructions accompanying the plate, the disks must be focussed in succession, observing in each case the quality of the image in the centre of the field, and the variation produced by using alternately central and very oblique illumination. When the objective is perfectly corrected for spherical aberration for the particular thickness of cover-glass under examination, the outlines of the markings in the centre of the field will be sharp by oblique illumination, and without any nebulous doubling or indistinctness of the minute irregularities of the edges. If, after exactly adjusting the objective for oblique light, central illumination is used, no alternation of the focus should be necessary to show the outlines with equal sharpness.

If an objective fulfills these conditions with any one of the disks it is free from spherical aberration when

used with cover-glasses of that thickness. On the other hand, if every disk shows nebulous doubling or an indistinct appearance of the edges of the lines with oblique illumination, or if the objective requires a different focal adjustment to get equal sharpness with central as with oblique light, then the spherical correction of the objective is more or less imperfect.

Nebulous doubling with oblique illumination indidicates over-correction of the marginal zone, indistinctness of the edges without marked nebulosity indicates under-correction.

The test for chromatic aberration is based on the character of the color-bands which are visible with oblique illumination. With good correction the edges of the lines in the centre of the field should show only narrow color-bands in the complimentary colors of the secondary spectrum, namely on one side yellow-green to apple-green, and on the other violet to rose. The more perfect the correction of the spherical aberration the clearer this color-band appears.

For the examination of objectives of smaller aperture (less than 40° or 50°), we may obtain all the necessary data for the estimation of the spherical and the chromatic corrections by placing the concave mirror so far laterally that its edge is nearly in the line of the optic axis, the incident cone of rays then filling only one-half of the aperture of the objective, by which means the sharpness of the outlines and the character of the color-bands can be easily estimated. Differences in the thickness of the cover-glass within the ordinary limits are scarcely noticeable with such objectives.

It is of fundamental importance in employing this test-plate to have brilliant illumination and to use an eye-piece of high power. With oblique illumination the light

must always be thrown perpendicularly to the direction of the lines.

When, with practice, the eye has learned to recognize the finer differences in the quality in the outlines of the images, this method of investigation gives very trustworthy results. Differences in the thickness of cover-glasses of 0.01 to 0.02 mm. can be recognized with objectives of two or three mm. focus.

Objectives are commonly more nearly free from spherical aberration in the centre than at the periphery. It is for this reason that when a minute object is to be examined with a high-power, the advice always given is to bring it to the centre of the field. This must be specially remembered when measuring objects that extend too near the sides of the field, since the spherical aberration of the lateral portions of the lens has the effect of increasing or of dimnishing the amplification, and the measurement will not be correct if the aberration is at all marked. This result of spherical defect is usually very noticeable in what is called flatness of field.

Flatness of Field.

Occasionally the field, instead of appearing as a flat or level plane, seems to be like the inside or the outside of a shallow cup, and although this is one result of

spherical aberration, the latter alone cannot be justly blamed. In some objectives the curvature is so great that the focus must be changed to a very perceptible extent before marginal objects can be clearly seen, after which the central portions become indistinct. This curvature should be as slight as possible, although, since it cannot be entirely eliminated, except by the use of apochromatic glass and of special eye-pieces it must be endured.

It may, as stated by Mr. Edward Bausch be due to a defective eye-piece. This may be determined by observing whether it shows equally with different objectives, and by using different eye-pieces, but of the same focal length, with the same objectives. And Mr. Bausch gives good advice when he says that in two objectives, if the predominant feature of one be resolving power, and of the other flatness of field, select the former.

A simple method of testing the flatness of the field is to strew starch-grains over a slide, and to observe whether the centre and the periphery of the field of view are in exactly the same focus at the sime time. If the centre is focussed and the margin appears hazy and indistinct, as it probably will appear even with the best objectives, the field is not perfectly flat. Similarly minute substances, as minute bacteria, strewn over the lower surface of the cover-glass will tell the same story with high-power objectives. Perfect flatness of field, even with the best of lenses, does not exist.

Professors Naegeli and Schwendener give the following method for testing this feature in objectives. A cover-glass with a straight edge is placed upon the diaphragm of the eye-piece (the eye lens having been removed), so that the edge shall appear in the circular opening of the diaphragm as a chord of arc. The real

image of another straight line, which is viewed as an object, is made to coincide with this chord precisely as the adjustment of a particular division-line to the margin of an object is effected in micrometric measurements. If a complete coincidence takes place—whether or not they appear straight or curved in the virtual image—then the real image is free from distortion; in all other cases it is distorted.

Angular Aperture.

The older opticians defined angular aperture to be the angle at the apex of a triangle whose base is represented by the width of the front lens of the objective, its two sides being the most oblique rays of light which can pass through that objective from a point in the object when focussed, that point being at the apex of the triangle. But as the result of the investigations made by Professor Abbe of Jena, objectives are now rated according to what he has named the Numerical Aperture (N. A.). This is one-half of the sine of the angular aperture multiplied by the refractive index of the medium in which the objective is used, which may be air, as it must be for a dry objective, water, glycerine or some homogeneous-immersion fluid.

The refractive index of air is taken to be 1.000; of water it is 1.333; of glycerine, 1.475; of oil of cedar, 1.510; of Canada balsam, 1.540; of styrax, 1.582; of crown glass, 1.51 to 1.53.

The angular or the numerical aperture may be obtained by the simple methods described in another place, or the N. A. may be ascertained from the following table when the angular aperture has been learned from the optician. The list is taken from "The Journal of the Royal Microscopical Society," for which it was prepared by Mr. J. W. Stephenson, to whom microscopists owe the use of homogeneous-immersion objectives, as he was the first to suggest a practicable means of utilizing the optical principle involved in their construction and employment.

A glance at the table will show how to use it to ascertain the N. A. If a dry objective have an angular aperture of 125° (in the column headed "Air"), it should correspond in resolving power and in some other good qualities, with a water-immersion having an angular aperture of 84°, and with a homogeneous immersion of 71°, while its N. A. will be 0.89.

APERTURE TABLE.

Numerical Aperture.	*Air.*	*Water.*	*Homogeneous Immersion.*
1.52	..	..	180° 0′
1.51	..	..	166° 51′
1.50	..	..	161° 23′
1.49	..	..	157° 12′
1.48	..	..	153° 39′
1.47	..	..	150° 32′
1.46	..	..	147° 42′
1.45	..	..	145° 6′
1.44	..	..	142° 39′
1.43	..	..	140° 22′
1.42	..	..	138° 12′
1.41	..	..	136° 8′
1.40	..	..	134° 10′
1.39	..	..	132° 16′
1.38	..	..	130° 26′
1.37	..	...	128° 40′
1.36	..	..	126° 58′
1.35	..	..	125° 18′
1.34	.	..	123° 40′
1.33	..	180° 0′	122° 6′
1.32	..	165° 56′	120° 33′
1.31	..	160° 6′	119° 3′
1.30	..	155° 38′	117° 35′
1.29	..	151° 50′	116° 8′
1.28	..	148° 42′	114° 44′
1.27	..	145° 27′	113° 21′
1.26	..	142° 39′	111° 59′
1.25	..	140° 3′	110° 39′
1.24	..	137° 36′	109° 20′
1.23	..	135° 17′	108° 2′
1.22	..	133° 4′	106° 45′
1.21	..	130° 57′	105° 30′
1.20	..	128° 55′	104° 15′
1.19	..	126° 58′	103° 2′
1.18	..	125° 3′	101° 50′
1.17	..	123° 13′	100° 38′
1.16	..	121° 26′	99° 29′

APERTURE TABLE—*Continued.*

Numerical Aperture.	*Air.*	*Water.*	*Homogeneous Immersion.*
1.15	..	119° 41′	98° 20′
1.14	..	118° 0′	97° 11′
1.13	..	116° 20′	96° 2′
1.12	..	114° 44′	94° 55′
1.11	..	113° 9′	93° 47′
1.10	..	111° 36′	92° 43′
1.09	..	110° 5′	91° 38′
1.08	..	108° 36′	90° 34′
1.07	..	107° 8′	89° 30′
1.06	..	105° 42′	88° 27′
1.05	..	104° 16′	87° 24′
1.04	..	102° 53′	86° 21′
1.03	..	101° 30′	85° 19′
1.02	..	100° 10′	84° 18′
1.01	..	98° 50′	83° 17′
1.00	180° 0′	97° 31′	82° 17′
0.99	163° 48′	96° 12′	81° 17′
0.98	157° 2′	94° 56′	80° 17′
0.97	151° 52′	93° 40′	79° 18′
0.96	147° 29′	92° 24′	78° 20′
0.95	143° 36′	91° 10′	77° 22′
0.94	140° 6′	89° 56′	76° 24′
0.93	136° 52′	88° 44′	75° 27′
0.92	133° 51′	87° 32′	74° 30′
0.91	131° 0′	86° 20′	73° 33′
0.90	128° 19′	85° 10′	72° 36′
0.89	125° 45′	84° 0′	71° 40′
0.88	123° 17′	82° 51′	70° 44′
0.87	120° 55′	81° 42′	69° 49′
0.86	118° 38′	80° 34′	68° 54′
0.85	116° 25′	79° 37′	68° 0′
0.84	114° 17′	78° 20′	67° 6′
0.83	112° 12′	77° 14′	66° 12′
0.82	110° 10′	76° 8′	65° 18′
0.81	108° 10′	75° 3′	64° 24′
0.80	106° 16′	73° 58′	63° 31′
0.79	104° 22′	72° 53′	62° 38′

APERTURE TABLE—*Continued.*

Numerical Aperture.	*Air.*	*Water.*	*Homogeneous Immersion.*
0.78	102° 31′	71° 49′	61° 45′
0.77	100° 42′	70° 45′	60° 52′
0.76	98° 56′	69° 42′	60° 0′
0.75	97° 11′	68° 40′	59° 8′
0.74	95° 28′	67° 37′	58° 16′
0.73	93° 46′	66° 34′	57° 24′
0.72	92° 6′	65° 32′	56° 32′
0.71	90° 28′	64° 32′	55° 41′
0.70	88° 51′	63° 31′	54° 50′
0.69	87° 16′	62° 30′	53° 59′
0.68	85° 41′	61° 30′	53° 9′
0.67	84° 8′	60° 30′	52° 18′
0.66	82° 36′	59° 30′	51° 28′
0.65	81° 6′	58° 30′	50° 38′
0.64	79° 36′	57° 31′	49° 48′
0.63	78° 6′	56° 32′	48° 58′
0.62	76° 38′	55° 34′	48° 9′
0.61	75° 10′	54° 36′	47° 19′
0.60	73° 44′	53° 38′	46° 30′
0.59	72° 18′	52° 40′	45° 40′
0.58	70° 54′	51° 42′	44° 51′
0.57	69° 30′	50° 45′	44° 2′
0.56	68° 6′	49° 48′	43° 14′
0.55	66° 44′	49° 51′	42° 25′
0.54	65° 22′	47° 54′	41° 37′
0.53	64° 0′	46° 58′	40° 48′
0.52	62° 40′	46° 2′	40° 0′
0.51	61° 20′	45° 6′	39° 12′
0.50	60° 0′	44° 10′	38° 24′
0.48	57° 22′	42° 18′	36° 49′
0.46	54° 47′	40° 28′	35° 15′
0.45	53° 30′	39° 33′	34° 27′
0.44	52° 13′	38° 38′	33° 40′
0.42	49° 40′	36° 49′	32° 5′
0.40	47° 9′	35° 0′	30° 31′
0.38	44° 40′	33° 12′	28° 57′
0.36	42° 12′	31° 24′	27° 24′

APERTURE TABLE—*Continued.*

Numerical Aperture.	*Air.*	*Water.*	*Homogeneous Immersion.*
0.35	40° 58′	30° 30′	26° 38′
0.34	39° 44′	29° 37′	25° 51′
0.32	37° 20′	27° 51′	24° 18′
0.30	34° 56′	26° 4′	22° 46′
0.28	32° 32′	24° 18′	21° 14′
0.26	30° 10′	22° 33′	19° 42′
0.25	28° 58′	21° 40′	18° 56′
0.24	27° 46′	20° 48′	18° 10′
0.22	25° 26′	19° 2′	16° 38′
0.20	23° 4′	17° 18′	15° 7′
0.18	20° 44′	15° 34′	13° 36′
0.16	18° 24′	13° 50′	12° 5′
0.15	17° 14′	12° 58′	11° 19′
0.14	16° 5′	12° 6′	10° 34′
0.12	13° 47′	10° 22′	9° 4′
0.10	12° 29′	8° 38′	7° 34′
0.08	9° 11′	6° 54′	6° 3′
0.06	6° 53′	5° 10′	4° 32′
0.05	5° 44′	4° 18′	3° 46′

To Measure Angular Aperture.

The optician usually engraves the angle of aperture on the mounting of the best objectives, and with the immersion lenses this will be the numerical aperture (N. A.). For the correctness of the measurement the microscopist may trust the optician, yet he may readily

measure the angle for his own satisfaction, by methods, which, although perhaps not as accurate as those of the manufacturer, are sufficiently so for the needs of the amateur.

If the microscope-stand have a graduated, revolving platform beneath the pillars, nothing else will be needed except a candle which should be placed at one end of the table, and so that the flame shall be about on a level with the objective to be measured when the microscope is in a horizontal position. Remove the mirror and all sub-stage apparatus, place the ocular in position, and when the field has been evenly lighted, rotate the horizontal instrument to one side until one-half the field is dark, the line of demarkation between the light and the dark halves being made as nearly central and perpendicular as possible. The graduation on the base of the stand will be one-half of the angle of aperture (not the numerical aperture), and may be verified by rotating the microscope to the other side, and again bisecting the field with the shadow, when the reading should give the same degree.

The value of the reading has been said to be one-half of the angle of aperture, but this is contingent upon the arrangement of the graduations. If the instrument was at zero at the beginning of the experiment, this holds good; but if the platform is so graduated, as it is with some stands, that the starting point cannot conveniently be at zero, then the instrument must be rotated in both directions, and the difference therefore of the graduations will be the angular aperture. On my own stand the graduations begin at zero and advance both ways, so that a low-power objective just measured, gives 5° when rotated to one side, the aperture consequently being ten degrees. For the sake of verifying

this result, the base was so turned that the rotation began at 50°. When one-half the field was bisected, the graduation marked 56°; when rotated in the other direction, the instrument stood at 46°, the difference giving the same angle as in the former experiment.

If the stand have no graduated platform, the entire instrument, in the same conditions and in the same position, may be rotated. On a sheet of paper draw a circle whose diameter is equal to the greatest length of the foot of the stand. Rotate the microscope within this circle until the field is exactly bisected, and mark the paper against one side of the foot; rotate it in the opposite direction, and when the other side of the field is again bisected, make against the same side of the foot another mark on the paper. Extend these two lines until they meet, and measure the included angle with the common protractor. This will give the angular aperture of that objective in air.

The accuracy of all these measurments will depend entirely upon the experimenter's carefulness in bisecting the field of the objective, and in measuring the angle with the protractor. Slight errors at the beginning will have a painfully conspicuous appearance at the end.

Should the reader unfortunately have a stand without a joint for inclination, he may still measure the angles of his dry lenses by a method suggested by an anonymous writer. With the microscope placed in a vertical position on a table, preferably a table with a dark-colored cover, the eye-piece, the mirror and all the sub-stage apparatus are to be removed. Rack down the body-tube until the objective passes as far as possible through the stage-opening. Place two pieces of white card one on each side of the instrument, and

while looking down the body-tube, move them back and forth until both can be just seen at the opposite and outer edges of the field of the objective. Measure the distance from the inside margin of one card to the inside margin of the other, and the distance of the front of the lens from the table. Draw the first mentioned distance as a horizontal base-line, and the latter as a perpendicular to its centre. Connect both sides of the base with the top of the vertical line, and the angle at the apex, or more correctly the two angles formed with the perpendicular at the apex of the triangle, will represent the aperture of the objective, and may be measured with the protractor.

The adjustment-collar usually has an influence in this connection. When the objective is to be measured for angle, the adjustment should be at or near closed, as that is usually the point of maximum aperture.

For the purpose of measuring angular aperture the optician and the students of microscopical optics employ a special apparatus termed an apertometer, of which there are several forms in use and with which the end desired may be attained with great accuracy.

The Abbe Apertometer.

The simplest, perhaps the best apertometer, at least the best-known, is that devised by Professor Abbe, of Jena, and made by the accomplished optician, Carl Zeiss and by his successors. It consists of a heavy,

semi-circular disk of glass graduated on its bevelled edge, and bearing two movable metal clips, one on each side, which mark the limits of the aperature in a way similar to that already described in the simple methods for measuring aperture referred to on a preceding page. A low-power objective accompanies the apparatus. The disk is placed on the horizontal stage of the microscope, the objective to be measured being focussed over a central spot on its surface, when the metal clips are to be moved on each side essentially as already described, and the angle is read off between the clips. The apparatus is useful if the microscopist have many objectives to measure, as a manufacturing optician or a dealer might have, but to the general reader it would be merely an optical luxury, to be possessed if he be wealthy, but not to be specially desired if he must be a little economical. The angular aperture may be ascertained by any of the simple methods already detailed, and the numerical aperture read off from the table given on another page.

Many objectives, perhaps the majority of even first-class objectives, admit rays of light around and from near the margins of the lens which have no part in the formation of the image, except in some cases to produce an imperfect result by their interference with the rays which enter into and emerge from the more nearly central area of the lens. These oblique rays do not reach the same focus which the more central rays reach, the result being a possible deterioration in the perfect action of the objective. Yet when measuring their lenses for angular aperture, the majority of opticians measure not only the more central, but also the marginal rays which may have a bad influence on the objective's action. This is not quite fair to the purchaser

yet it is commonly done. It is done by all opticians, so far as I have been able to learn, except by the late Robert B. Tolles, of Boston, and by Mr. Herbert Spencer of the Spencer and Smith Optical Company, of Buffalo, N. Y. These two accomplished opticians measure only the rays which are truly image-forming. This method of ascertaining the angular aperture of an objective originated with the late R. B. Tolles, and is an eminently honest and praiseworthy manner of dealing not only with the objective, but with the purchaser who puts his trust in the manufacturing optician, and has no kind feelings toward that man when he is deceived. The majority of objectives when measured by the image-forming rays only, will be reduced in angle in a way that will be painful to the unsuspecting owner. The usual method, the one which has thus far been been described in the preceding pages, measures not the true angular aperture, although it is always called by that name, but it measures the angle of the field, quite another thing, because the field will include all the rays that pass through the objective, the extreme marginal ones as well those that are more central and image-forming. Thus a good objective in my possession, claiming an angular aperture of 135°, which it has when it is measured for what is practically the angle of the field, has, when measured for the image-forming rays, an angle of only about 96° ! Still, it is an excellent objective and may be recommended; yet it might be as confidently commended if the maker had told the truth about it, or at least had given the real facts in the case.

The method of measuring this true angle of aperture does not materially differ from that already described. The only essential difference is that the objective is focussed on an object while it is being measured, and

the angle is read as soon as the image begins to be changed for the worse. The procedure demands rather more care and skill than that already described, but the owner of what claim to be wide-angled objecjectives will be rewarded if he teach himself the necessary skill for his own personal satisfaction. The matter has been especially studied by Dr. George E. Blackham, of Dunkirk, N. Y., who has called the attention of microscopists to the subject, and has published the details of his method of making the measurement. The following paragraphs are chiefly from Dr. Blackham's paper.

The objective to be measured is attached to the microscope with the eye-piece in place, exactly as for ordinary work, and is focussed on some suitable object in the centre of the field, the correction collar being used if necessary to get the best image the objective is capable of giving. The object should be a transparent one, the resolution of which is a fair test of the powers of the lens. After these arrangements have been completed, the body of the microscope is turned to a horizontal position, the mirror swung out of the way, and the object illuminated from below the stage by a narrow radiant, such as the flame of a toy candle. The source of illumination is then moved to the right and the left in succession, till either the centre of the field becomes darkened or the image is spoiled. The angular value of this distance through which the source of illumination can be moved before this takes place, is the available angular aperture of the lens; that is, the useful aperture for definition. In some lenses the image is spoiled long before the centre of the field is darkened, so that the aperture, for the mere transmission of light, is much greater than that for definition. Such

lenses are imperfectly corrected for the marginal rays and their performance can be improved by cutting off these aberrant marginal rays by means of diaphragms, and so reducing their angular aperture (for transmission).

Instead of moving the candle as Dr. Blackham suggests, the microscope may be turned on the graduated base which some stands have, or the angular value may be ascertained by some of the other methods previously described, and which are rather easier for most experimenters than to make the estimates and calculations demanded by Dr. Blackham's method. Or if the mirror-bar be graduated and capable of being swung to one side, as Dr. Blackham says it should be (in which we all agree with him), the microscopist has a means of reading the obliquity to which it is swung by substituting a toy candle for the mirror and rotating it to one side instead of moving the candle alone as in the other plan, or of turning the microscope on its base.

If greater accuracy be desired, it can be secured by the use of an opaque slide with a transparent line across it, in which the objects are mounted, and this line can be so placed on the stage as to bisect the field of view very accurately in a vertical direction, and the exact moment at which the centre of the field is darkened can thus be determined with greater precision. Such a slide can readily be made by cutting a 3x1 inch slip from a photographic plate, exposing it to the full sunlight, developing and fixing it, and then drawing a sharp knife across it on the film side. In the transparent line thus made, diatoms or any other objects may be mounted in balsam and covered in the usual way.

The plan of measurement here described, if used without any devices below the stage, can measure aper-

tures only below 1.00 numerical aperture; that is to say, angular apertures of 180° air, of 97° 31′ water, or of 82° 17′ in glass or homogeneous immersion-fluid, and must always give the results in terms of the equivalent air-angle. Hence when we have occasion to measure the aperture of a lens exceeding, or indeed closely approaching 1.00 N. A., it becomes necessary to use below the stage some device like the little hemispherical lens, which being attached to the under side of the slip by an immersion contact, allows the rays to pass into the slide without refraction, and consequently gives the angle in terms of the glass, or the homogeneous angle.

It not rarely happens that the manufacturing optician does not mark on the mounting of his objectives the aperture that the purchaser thinks should be there, after the purchaser has measured it. This refers, of course, to the aperture that includes all the entering light, the marginal as well as the image-forming rays. The optician will never use half a degree, as there is no reason why he should; and he does not seem to care much about odd numbers, as shown in the following table of angular and numerical aperture of the objectives mentioned, which were all measured with an Abbe apertometer in the expert hands of Prof. M. D. Ewell, of Chicago; from whose report the list is taken.

Table of the Aperture of Certain Objectives.

Maker.		Description.	Aperture claimed by maker.	Aperture as measured.
Bausch & Lomb,		Professional 1 in.	36°	30°
"	"	½ in.	60°	61°
"	"	2 in., first class.	22°	21°
"	"	¼ in., students.	75°	70°
"	"	$\frac{1}{5}$ in., students.	110°	95½°
"	"	$\frac{1}{6}$ in., first class.	140°	114°
"	"	$\frac{4}{10}$ in., first class.	110°	111°
"	"	$\frac{1}{8}$ in., hom. imm.	N. A. 1.43	N. A. 1.28
Beck,		$\frac{1}{5}$ in., first class.	100°	98°
Crouch,		1 in.	25°	24°
Grunow,		$\frac{1}{6}$ in	140°	150° closed 147° open.
Gundlach,		$\frac{1}{8}$, hom. imm.	N. A. 1.41	N. A. 1.39
Hartnack.		½ in.	40°	47°
Leitz,		18 mm., No. 3, dry.	N. A. 0.28	N. A. 0.28
"		32 mm., No. 7, dry.	N. A 0.85	N. A. 0.88
"		$\frac{1}{12}$ in., oil imm.	N. A. 1.30	N. A. 1.28
Spencer & Co.,		¼ in., students.		94°
"	"	$\frac{1}{10}$ in., hom. imm.	B. A. 130°	N. A. 1.36
"	"	$\frac{1}{25}$ in., " "	B. A. 125°	N. A. 1.32
Spencer & Smith,		$\frac{4}{10}$, first class.	130°	126°
"	"	$\frac{1}{8}$, first class, dry.	150°	167°
"	"	$\frac{1}{10}$ in, hom. imm.	B. A. 138°	N. A. 1.41
"	"	1 in.	33°	32½°
"	"	½ in.	70°	71°
"	"	$\frac{1}{12}$, hom. imm.	N. A. 1.00	N. A. 0.97
Tolles,		$\frac{1}{6}$, hom. imm.	N. A. 1.32	N. A. 1.31
"		2 in.	Unknown	12½
"		$\frac{1}{12}$ in, water imm.	"	0.99 closed 0.90 open
Zeiss,		$\frac{3}{5}$, A A.	36°	31°
"		¼, C C.	90°	102°
"		$\frac{1}{18}$, hom. imm.	N. A. 1.27	N. A. 1.27

To Measure Numerical Aperture (N. A.).

For the measurement of numerical aperture, the late Dr. Allen Y. Moore used a method whose application was probably original with himself. The following is his description. A low-power objective (a three-inch or a four-inch is convenient for the purpose), is attached to the microscope, and the latter placed in a horizontal position. The objective whose numerical aperture is to be measured is screwed into the sub-stage with its front facing toward the mirror which should be turned as far as possible to one side, or preferably removed from the stand. If now the microscope be properly focussed, a bright disk of light will be seen, and will represent the acting diameter of the back lens of the objective in the sub-stage. The camera lucida should be attached to the eye-piece, and the diameter of this disk marked on paper. A hemispherical lens is now to be applied to the front of the objective to be measured, and should have immersion contact with it, that is, should be attached by means of a drop of glycerine or of homogeneous-immersion fluid. This will enlarge the bright circle to the full aperture of the objective, and this bright disk should also be drawn on the paper. Remove the objective from the sub-stage, and on the microscope-stage place a micrometer ruled to thousandths of an inch, and with the camera lucida project these lines upon the two circles on the paper, thus measuring their diameter. If the diameter of the larger circle be divided by that of the smaller, the quotient will be the numerical aperture This applies however, only to objectives whose N. A. is greater than 1.00.

Definition.

The definition, or the defining power, of an objective, is its ability to produce an image of the object examined that shall be clear, sharp, crisp and true. The outlines of the image, as has already been remarked, should be so distinctly defined that they shall be as sharply marked as the lines of a copper-plate engraving, and the structure of the object must at the same time be as clearly defined as is the contour.

The greater the angular aperture the more perfect and satisfactory will be the definition. Small-angled objectives have some qualities that make them more easily manipulated by the novice, but the exquisite definition of the wide-angled glasses is not one of them; and the wide-angled lenses lack the element of penetration, or depth of focus, possessed by the smaller-angled objectives and valued to a certain extent in some investigations.

There are many tests for the definition of low and of medium powers of small angle. For the former, Mr. E. M. Nelson, an accomplished British microscopist, suggests the flattened proboscis of the blow-fly mounted in Canada balsam, and for the latter the minute hairs on the same object. Under medium powers of high angle, he recommends stained bacteria, and the diatom *Pleurosigma formosa* mounted in balsam.

According to Prof. Abbe, small fragments of the diatom *Pleurosigma angulatum* may be used to advantage as tests of even the best and widest angled immersion objectives. In connection with the illumination during the testing, he recommends that the mirror should be so arranged that the light shall just graze the centre of the front surface of the objective, the striæ of the diatom being at right angles to the general direction of

the illumination; this tests the marginal zone of the lens. The mirror is then to be shifted laterally so as to produce the most oblique illumination. In both cases the outlines and the structural striæ should not only appear equally sharp, but should coincide without difference of level and without lateral displacement. If an objective fulfills these requirements, at least in the centre, says Professor Abbe, it may be depended upon to produce accurate images. An intermediate position of the mirror would furnish additional proof that the different zones co-operate simultaneously in the production of the images.

Resolving Power.

The resolution, or the resolving power, of an objective is its ability to separate fine and close markings or lines, such as the striæ on the diatoms, or those closely ruled lines on the artificial test-plates of various makers. This ability depends upon certain qualities of the lens, especially upon the numerical aperture, and not upon magnifying power. In the separating of very fine and close lines it is customary to use high-power eye-pieces, not because the increase in magnifying power increases the resolving power of the objective, but because it separates the lines a little wider so that the eye may more easily see them.

The reader should remember that to do much in the resolving of diatoms or of fine rulings, the eye must be specially educated for the work. Whilst the microscopist may be expert in the use of his objectives and illuminating apparatus, and whilst he may be a learned histologist, or an accomplished investigator in some other department of science, he may not be able to exhibit fine lines or diatom-striæ, either to himself or to his friends. This is a special department in which special eye-training is demanded. And whilst it is well to be able to resolve the most difficult diatoms, so as to be able to know positively by one's own experience what a certain objective will do, it should not be the chief aim in the microscopist's life. The resolving of diatoms is useful in studying the manipulation of the objective, and important in comparing the action of different objectives from different makers, and with different angles of aperture, but there are many things more important than these "microscopical gymnastics." It is exceedingly important that the owner of good objectives should study them to learn what they will do, and how he may obtain the best results from them, but to know no more of microscopical research than is contained in an attempt to force one objective to resolve a few lines more than another, seems a poor compensation for the time, labor and expense, when the world is teeming with innumerable things about which we know nothing, and when even one little corner of one little field of investigation, well cultivated with the microscope, will bring the cultivator fame, and the scientific world increase of happiness through increase of knowledge.

The resolving power of a well-corrected objective depends upon its numerical aperture. A lens of wide aperture will show finer and closer lines than will a small-

angled glass, the resolution increasing and diminishing in a certain proportion as the numerical aperture is enlarged or contracted, all objectives that have the same numerical aperture having the same resolving power.

The character of the illumination, whether central or oblique, is an important element. Oblique light will bring out markings not visible with central illumination, and the objective that will resolve *Pleurosigma angulatum* with central light, other things being equal, is a better lens than the one that resolves it only with oblique illumination.

The adjustment of the objective is also of great importance in this connection. And the medium in which the test is immersed has great influence. A diatom mounted dry is more easily resolved than the same diatom in Canada balsam. The character of the lines or of the dots is important to the success of the work. Two diatoms may have the same number of lines to the fraction of an inch, yet one may be easily resolved, whilst the other may tax the resources of the best objectives and all the microscopist's skill, because the striæ on one are strongly developed, while those of the other are faint, low and delicate. The same holds true to a certain extent with ruled lines. The stronger and deeper, and the better filled with graphite these cuts in the glass may be, the more easily are they resolved by the proper objective, or at least, the more easily are they seen by the eye.

Although diatoms of the same species differ to some extent in the character and often in the number of their striæ, they are the most accessible tests for resolution that we have. They are used by all microscopists and by the opticians, as they form a ready means of comparison. A convenient collection is Möller's or

Thum's test-plate (Probe Platte) consisting of a slide of twenty diatoms arranged in a line according to the difficulty of their resolution, beginning with *Triceratium favus* and ending with *Amphipleura pellucida*. The slides may be had balsam-mounted or dry. These preparations are somewhat costly, and the reader may as readily and at less expense supply himself with several slides of different tests, with the advantage of having many of the same form on the slide in many different positions, and probably of different degrees of fine striation.

The microscopist that desires to test his objectives, and to train his eye to see fine lines and dots, should purchase balsam-mounted slides of *Pleurosigma angulatum*, *Frustulia Saxonica*, *Surirella gemma*, *Amphipleura pellucida*, or, if he studies convenience rather than expense, a test plate by Möller or by Thum. But with the diatoms mentioned he will have enough to test the best and highest-angled objectives. *Pleurosigma angulatum* may serve as a test for the one-fourth or the one-fifth inch objective, which should resolve the transverse lines with central light, and three sets, one transverse and two oblique in opposite directions, under the proper illumination. A four-tenths inch by Mr. Tolles in my possession will resolve this diatom in beads when mounted in styrax, as well as exhibit the transverse striæ on a dry *Surirella gemma*.

Frustulia Saxonica is more difficult, that is, the striæ are finer and much closer together than those of *P. angulatum*, demanding a high-power of wide angle to resolve them. A one-sixth or one-eighth of fine quality will be needed to conquer them.

Amphipleura pellucida is the most difficult of the known diatom tests. Photography has recently resolved

it into dots or beads, but to show the exceedingly fine and delicate transverse striæ only, is a labor for the best of ordinary modern objectives, although the majority of the recent lenses of wide aperture will do the work easily, if properly treated. The diatom has been resolved into beads by Powell and Lealand's $\frac{1}{8}$ inch objective, and by the remarkable new apochromatic $\frac{1}{10}$, 1.63 N. A. by Zeiss, in the hands of Dr. H. Van Heurck.

Oblique light is always necessary for this kind of work; it is often needed so oblique that the upper edge of the mirror, when swung to one side, is only a little below the surface of the stage. The concave mirror should be carefully focussed on the object, and the diatom so placed that the striæ desired to be shown shall be at right angles to the direction of the illumination, and the position of the adjustment-collar must be carefully and frequently changed until the best results are attained. Daylight is not adapted to such work. Direct sunlight should never be used.

In the study of the striæ of diatoms the mirror alone is often not sufficient. In all such work the hemispherical lens is a useful accessory, concentrating the light on the diatom, and adding somewhat to its intensity. This lens is simply a little button of glass about half an inch in diameter, and of the proper curvature to focus the light upon the object. It is attached to the lower surface of the slide by a drop of water, of glycerine or of homogeneous-immersion fluid. If too much liquid be used the lens will slip out of position when placed on the inclined stage. Use only enough therefore to hold it firmly and to expel all the air from between it and the slide to which it is attached.

The following table gives a list of the diatoms on Möller's test-plate, with the number of striæ to the

inch. *Eupodiscus argus* begins and ends the line so that it may be readily found.

	Diatom.	Striæ in 1-1000 inch.
1.	*Triceratium favus* Ehr. - -	3.1 to 4.0
2.	*Pinnularia nobilis* Ehr. - -	11.7 to 14.0
3.	*Navicula lyra* Ehr. var. - -	14.5 to 18.0
4.	*Navicula lyra* Ehr. - - -	23.0 to 30.5
5.	*Pinnularia interrupta* Sm. var. -	25.5 to 29.5
6.	*Stauroneis Phœnicenteron* Ehr. -	31.0 to 36.5
7.	*Grammatophora marina* Sm. - -	36.0 to 39.0
8.	*Pleurosigma Balticum* Sm. - -	32.0 to 37.0
9.	*Pleurosigma acuminatum* (Kg.) Gr.	41.0 to 46.5
10.	*Nitzchia amphioxys* Sm. - -	43.0 to 49.0
11.	*Pleurosigma angulatum* Sm. - -	44.0 to 49.0
12.	*Grammatophora oceanica* Ehr. -	60.0 to 67.0
13.	*Surirella gemma* Ehr. - - -	43.0 to 54.0
14.	*Nitzchia sigmoidea* Sm. - - -	61.0 to 64.0
15.	*Pleurosigma fasciola* Sm. var. -	55.0 to 58.0
16.	*Surirella gemma* Ehr. - - -	64.0 to 69.0
17.	*Cymatopleura elliptica* Breb. - -	55.0 to 81.0
18.	*Navicula crassinervis* Breb. - -	78.0 to 87.0
19.	*Nitzchia curvula* Sm. - - -	83.0 to 90.0
20.	*Amphipleura pellucida* Kg. - -	92.0 to 95.0

The following is the list of the diatoms used on Thum's test-plate.

1. *Triceratium favus* Ehr.
2. *Navicula nobilis* Kutz.
3. *Navicula lyra* Ehr. var.
4. *Navicula lyra* Ehr.
5. *Pleurosigma attenuatum* Sm.
6. *Stauroneis Phœnicenteron* Ehr.
7. *Grammatophora marina* Sm.
8. *Pleurosigma Balticum* Sm.
9. *Pleurosigma acuminatum* (Kg.) Gr.

10. *Pleurosigma angulatum* Sm.
11. *Nitschia sigma* Sm.
12. *Surirella gemma* Ehr.
13. *Nitschia sigmodea* Sm.
14. *Nitschia obtusa* var. *Schweinfurthii* Gr.
15. *Cymatopleura nobilis* Hantz.
16. *Nitschia linearis* Sm.
17. *Grammatophora subtilis* Bail.
18. *Surirella gemma* Ehr.
19. *Frustulia Saxonica* Rahb.
20. *Amphipleura pellucida* Kg.

In addition to diatoms, microscopists are in the habit of using artificial tests in the form of exceedingly fine and close lines ruled on glass by a special machine. The most celebrated of these test-plates, those of the late F. A. Nobert, of Prussia, have already been referred to, the best known and most important being his slide bearing nineteen bands of lines, the number of lines in each band increasing and the spaces decreasing up to the last or nineteenth. The other plates by the same maker are seldom heard of at the present day.

The *Lepisma saccharina*, the markings on whose larger scales are as close together as the lines on the first band of this plate, is a common little insect often seen in old books or running actively in dark places. It is so elongated and flattened, and so silvery-gray in color, that it is frequently called the "silver-fish insect." The body has three bristle-like radiating caudal filaments and two thread-like antennæ, and when full-grown, may be fully an inch long. It is covered with scales which at one time were used as tests, and are still commendable for certain purposes. They should be mounted dry.

The following is Nægeli and Schwendener's list of diatoms whose lines correspond in number to the number of lines in each band of Nobert's nineteen-band plate.

Band.	Lines to 0.001 in.	Lines to mm.	Approximate equivalent.
1.	11.26	443	*Lepisma saccharina;* large scales.
2.	16.89	665	*Pinnularia viridis.*
3.	22.52	886	
4.	28.13	4108	
5.	33.78	1329	*Pleurosigma Balticum.*
6.	39.41	1550	" *attenuatum.*
7.	45.04	1773	
8.	50.67	1992	} *Pleurosigma angulatum.*
9.	56.30	2216	
10.	61.93	2439	*Grammatophora marina.*
11.	67.56	2653	*Nitzchia linearis.*
12.	73.19	2870	} *Navicula rhomboides.*
13.	78.82	3105	*Grammatophora subtilissima.*
14.	84.45	3322	
15.	90.08	3546	} *Frustulia Saxonica.*
16.	95.71	3768	*Amphipleura pellucida.*
17.	101.34	3989	
18.	106.97	4211	
19.	112.60	4433	

In "The English Mechanic," Mr. G. D. Hirst describes a method, not original with him, of intensifying the resolving power of an objective when used over close-lined tests. He says: Take, for instance, the diatom *Amphipleura pellucida*, and having got the best results obtainable with the illuminating apparatus at one's disposal, let the analysing prism of the polariscope be placed over the eye-piece, and rotated until it darkens the field, which it will do although not to the same extent as when used with the polarizing

prism. On carefully focussing the diatom, the lines will show themselves with an extraordinary increase of definition. Specimens that without the aid of the prism show only a washy sort of resolution, will now show the lines as black as the bars of a gridiron.

The application of the prism will of course not make an objective resolve a test beyond the reach of its aperture.

Penetration.

The penetrating power of an objective is its ability to show the structure of an object below the plane for which it is focussed; that is, the objective can penetrate to a certain distance into the object without being lowered by the focussing mechanism. It is of very little importance, and is incompatible with resolving power. It depends chiefly upon the numerical aperture, like so many other qualities of the objective, decreasing in a certain proportion with the increase of the aperture, and increasing as that diminishes.

One of the advantages of objectives with wide aperture (N. A.) is, that while they show the most delicate details of the surface for which they are focussed, there is no confusion by the introduction of a somewhat indistinct view of structure below that focal plane, yet the objec-

tive may, in certain conditions, be depressed for the satisfactory examination of an inferior plane of the object, with little interference with the superior surface just examined and left. With certain wide-angled glasses it is possible to produce optical sections of the object, by which the relations of structure may be satisfactorily demonstated.

Working-distance.

The working-distance of an objective is the distance between the lower surface of the front lens, when the objective is focussed, and the upper surface of the object, the practicable distance being reduced by the presence of the cover-glass. It varies according to the magnifying power and to the angular aperture, depending chiefly upon the latter. The optician can control it to a certain extent, making it, within certain limits, long or short at will, since it depends not only on the power and on the aperture, but upon the thickness of the lenses composing the objective, upon their curvature and their number.

Objectives are not named according to their working-distance. A one-inch objective will not have a one-inch working-distance, and the latter will not be one-tenth of an inch with a one-tenth inch microscope-lens Objectives are rated according to their power and their

focal length in comparison with single lenses. A one-inch objective is supposed to have the same magnifying power as a simple lens of one-inch focus, and a one-fifth inch objective to be the same in power as a simple lens having a focal length of one-fifth inch.

Working-distance is a convenient quality, since an objective of long working-distance is more easily used than one that focusses so close to the cover as to be almost in contact with it. In some cases however, it is an obstacle, especially in certain immersion-objectives where the optician has so increased it that the capillary attraction is scarcely sufficient to hold the immersion liquid in place between the lens and the cover. But this is not a common occurence.

To Measure Working-distance.

If the stand have a scale and vernier at the side of the body, and the front lens of the objective is flush with the mounting, the working-distance may be readily measured by carefully bringing the objective in contact with the slide, after which it is focussed on any imperfections or small particles on the surface, and the distance to which it has been raised is then to be read on the scale. In high-power objectives the distance may be ascertained by the fine-adjustment screw, if the milled-head is graduated and the lens flush with the

mounting, as it often is not. Yet the distance between the front of the mounting and the front of the lens is so short that it may be disregarded in the lower powers. In the higher, if a more accurate measurement is desired, it may be made by using two objectives.

In such cases, place the lens whose working distance is to be ascertained, in the substage so that the front faces upward, and arrange an object behind it until the small image is distinct at its focus. With a low-power objective on the microscope, focus on the face of the objective to be examined, and measure the distance through which the body-tube must be raised in order to get a distinct view of the image formed by the objective whose working-distance is to be ascertained.

When the working-distance of an adjustable objective is to be ascertained, the collar should be at or near closed point, unless the microscopist desires to know it both for covered and for uncovered objects, as it varies slightly under these conditions in which case he must measure it with the collar at both adjustments.

It varies also not only with every adjustment, since every movement of the collar changes the focus, but also according to the eye-sight of the observer, and the power of the eye-piece. A near-sighted microscopist must focus his objectives nearer the object, and thus shorten the working-distance, while the presbyopic observer usually lengthens it, especially when using lenses of low power. With high-powers the same fact holds good, but not to so great an extent.

Magnifying Power.

The magnifying power of the microscope depends upon the power of the objective and that of the eye-piece, and upon the length of the body-tube. It is ascertained by multiplying the power of the objective by the power of the ocular, the length of the body-tube being assumed to be of the standard length of ten inches. If the objective alone magnifies fifty diameters and the eye-piece five, the power of the combination will be two-hundred and fifty diameters. This is absolutely correct however, only when what is called optical tube-length, which is a very variable quality, has been taken into consideration. For the unchanging ten-inch body-tube it is not strictly accurate, yet it is near enough for all practical purposes.

The power of the objective depends upon its focal length, both increasing and diminishing together, while that of the microscope, or combination of objective and eye-piece, depends, in addition, upon the power of the ocular and the length of the body-tube, the longer the tube or the stronger the eye-piece, the greater the amplification. The power of the objective is also affected by the adjustment collar, increasing as the adjustment approaches the closed point and becoming greatest at that point.

If the objective is correctly named according to its focal length, its power will be the quotient of ten inches (the arbitrary distance of distinct vision, and the length of the body-tube), divided by the focal length; M (magnifying power)$=\frac{10}{f}$, where f is the focal length. Thus a one-inch objective should magnify ten diameters without the eye-piece; a one-fifth, $10 \div 0.2$ or fifty diameters; a one-tenth, one-hundred diameters.

But all objectives are not correctly named. Some

opticians in their nomenclature under-rate their productions, so that a lens marked $\frac{1}{4}$ by one maker may in reality be a $\frac{1}{5}$, and may do as much as or more than a one-fifth by another, to the honor and glory of the former apparently lower power. Such nomenclature is not only dishonest, but it is inconvenient and misleading when we wish to compare two objectives by different makers, but nominally of the same focal length. Opticians have been improving in this respect of late years. Formerly the complaints were many and bitter, and the opticians answered back, defending themselves or trying to do so, and thus making things lively. But the makers seem to have taken warning. At least the complaints have become fewer.

To measure the power of the objective, it is necessary to have a point from which to begin the measurement, and this, it is said, should be the optical centre, or "that point in a lens through which if a ray passes, it enters and emerges in parallel lines;" but since nobody knows where the optical centre may be, and since some objectives have none, it is rather difficult to find. Yet when it exists, it may be discovered by going through with three pages of mathematical calculations to get two or three formulæ which, when combined and solved, will give the point sought, and which, when obtained will be practically worthless.

A method which is sometimes more convenient is to measure from the posterior principal focus of the objective, and since this, in high-powers especially, is close to the surface of the back lens, the back lens may be taken as the starting point.

To obtain the distance of this posterior focus from the upper end of the body, prepare a paper tube closed at one end with a translucent diaphragm, and slip this

down the body until a small spot of light is sharply defined in the centre of the diaphragm. Where this spot is formed is said to be the posterior focal point of the objective. Mark the place on the outside of the body, and measure the tube-length from it. With low powers the length of the body-tube may be ten inches from the front lens, since the posterior focus in such lenses is higher up the body, for which the length of the lens-mounting will make approximate compensation.

In the experiment with the paper diaphragm the tube should be small enough to enter the mounting of the objective, as its posterior focus is often close to the back lens, frequently less than $\frac{1}{100}$ inch above it, when it is outside of the lenses; sometimes it is somewhere inside of the objective, in which case this experiment will fail, as the paper diaphragm cannot then reach the focal point. To be strictly accurate in these matters is difficult, often impossible to any but the opticians, and it is the optical tube-length that should be ascertained, yet this is a varying quantity with every combination of objective and eye-piece, since it is the distance between the posterior principal focus of the objective and the anterior principal focus of the ocular. The former it is often impossible to find in any practical way; the latter is usually at or near the diaphragm within the eye-piece tube. For all practical purposes, however, it will be amply sufficient to measure the distance from the back lens of the objective to the diaphragm of the eye-piece used, both positions being obtained without difficulty, as the diaphragm of the ocular is always fixed at the proper point by the optician.

The position of the posterior focus of the objective depends upon the construction given the lens by its

manufacturer. Sometimes it is outside of the combination and can then be ascertained; often it is somewhere within the objective, when we have no convenient means of getting at it. The late W. H. Bulloch, of Chicago, paid some attention to the subject, examining several objectives by different makers, his purpose being to discover a practicable method which might be employed by the microscopist that is not a manufacturing optician, nor an expert in the application of microscopical optics. His conclusion was that the use of the posterior principal focus of the objective was not possible, for the reasons already detailed.

His method of ascertaining this focal plane was to place the objective to be examined in the sub-stage of a microscope, with the front lens directed away from the microscope-stage. He then used a low-power objective on the body-tube to find the position of an image of a distant object formed by the lens in the sub-stage. I find much difference, he says, among the objectives of different makers; of those of about the same magnifying power, some have the posterior focus within the combination, others have it some distance behind the back system; for example, in the Spencer two-thirds inch of 36° the posterior focus was found to be 0.18 inch within the combination, measuring from the back lens; in another two-thirds of 30°, 0.34 inch behind the posterior combination.

These are short distances, but in work that is to be followed by mathematically accurate results, they are important; yet for the amateur microscopist they may be disregarded, and, as has been said, the back lens of an objective higher in power than the two-inch may be taken as the starting point for our measurements.

The following table is compiled from Mr. Bulloch's

paper, and is here given for the convenience of those possessing the objectives mentioned, and also to show that the distances are so short that they be disregarded by all except perhaps the professional, manufacturing optician.

Maker of Objective.	Name of Objective.	Angle of Aperture.	Posterior focus from front surface.	Posterior focus inside or outside the combination
Spencer,	$\frac{1}{10}$ hom. imm.	1.35 N. A.	0.145	inside
"	$\frac{1}{10}$ " "	1.27 N. A.	0.11	"
"	$\frac{1}{10}$ dry	imm. 170°	not found at open point: at closed 0.25	"
"	$\frac{1}{4}$ dry	115°	0.15	outside
"	$\frac{2}{3}$	36°	0.18 inside of back.	"
"	1 inch	40°	0.02 inside of back.	"
"	2 "		0.67	"
Gundlach,	$\frac{1}{18}$ imm.	105°	0.15	inside
"	$\frac{1}{8}$ hom. imm.	1.40 N. A.	0.53	"
"	$\frac{1}{8}$ dry	135°	0.43	"
Bausch & Lomb,	$\frac{1}{6}$ dry	140°	0.41	"
"	$\frac{1}{6}$ imm.	180°	not found	"
"	$\frac{1}{6}$ dry	110°	0.49	outside
"	$\frac{4}{10}$		0.15	inside
"	1 inch	36°	0.04 inside of back.	"
"	$\frac{1}{2}$ inch	98°	0.02	outside
Grunow,	$\frac{2}{3}$		0.85	"
"	$1\frac{1}{2}$		0.123	"
Zeiss,	$\frac{1}{6}$ (D D) dry	116°	0.41	inside
"	$\frac{1}{4}$ (C C)	90°	0.32	"
"	$\frac{3}{8}$ (A A)	20°	0.84	"
"	A* closed		8.53	outside
"	" at 5		7.8	"
"	" open		7.3	"
Queen & Co.,	2 inch	10°	1.57	"

The posterior principal focus of Zeiss's variable low-power objective A*, and that of Queen & Co.'s 2 inch, are so far outside of the combination of lenses forming the objective that the reader may measure the distance for his own satisfaction. For this purpose a bright light is needed, either sunlight or the parallel rays from the Acme lamp, from the Stratton Illuminator, or light from a lamp-flame made parallel by the interposition of a bull's-eye lens. The objective is then held with the front lens toward the source of illumination, which should be placed at the opposite side or end of the room, and the light focussed on the wall. The focal point will be represented by a minute, circular dot of light of great intensity and purity, the little spark being smaller than the head of the smallest pin. By moving the objective toward or from the wall, the exact focus may be readily obtained, as a slight movement will be sufficient to increase the size of the spot, and greatly to decrease its brilliancy. The distance from the front surface of the front lens to the wall, will be the distance of the posterior principal focus. This distance cannot be obtained in this way with any microscope objective higher in power than the two-inch.

As it is not always possible, and not often convenient, to ascertain the optical tube-length by actual measurement, Mr. A. Ashe has discovered a method of learning this optical distance by a simple act of observation and an equally simple calculation. By this plan the microscopist may know what optical tube-length he has in practical use without, as Mr. Ashe remarks, putting his finger at certain points of the body-tube and saying, Here is the posterior principal focus of the objective, and here the anterior principal focus of the eyepiece, and then measuring the distance between them

by a foot-rule. To know this optical distance, however, is always of great interest, often of much importance. For instance, by Mr. Ashe's admirable method, I have learned that with a certain combination of objective and ocular the actual optical tube-length is only a single inch, a fact that explains certain features in connection with this special objective that were otherwise more than obscure.

Mr. Ashe's method is, in his own words, as follows. A careful estimate is made of the power of the microscope with the draw-tube pushed home as far as it will go; then having determined this, the eye-piece is withdrawn three or four inches, the exact amount being noted and the increased power of the instrument remeasured.

We are now in possession of all the data necessary to calculate—not the actual optical tube-length, but its arithmetical equivalent—a distinction to be observed, though the difference is immaterial to the purpose in view.

As it is a rule in optics that the relative sizes of images formed by a lens at different points in its axis are in strict proportion to the distance of those points from the focus of the lens, we may arrange the following formula:

$$\frac{AB}{C}=D$$

where A is the amplification of the instrument with the draw-tube closed; B the distance to which the eye-piece has been withdrawn; C the increase in power produced by the effect of B. D is therefore the equivalent of the distance separating the focus of the objective from the anterior focal plane of the ocular.

To illustrate this simply, suppose an instrument mag-

nifies 100, and that on withdrawing the eye-piece three inches, the power is found to be increased to 130, the equivalent of the tube-length will be, by the foregoing rule, $\frac{100 \times 3}{30} = 10$, or ten inches.

A simplification of this method has recently been recommended by its author. It is as follows:

Instead of measuring the power of the microscope twice over, it is sufficient to place a micrometer, or other divided scale, on the stage, and to count the number of lines that fill the field of view from side to side, then to pull out the draw-tube some inches and repeat the counting.

Of course the greater the increase in power the fewer will be the number of lines seen. In other words, the number of lines and the magnifying power are in inverse proportion to each other.

Now, for the purpose in view, it does not matter one iota what the actual powers of the instrument may be, with its draw-tube in various positions, so long as we know the proportion those powers bear to each other, and this proportion we shall find in the relative number of lines which fill the field of view at the same points.

Hence (bearing in mind the inversion of the ratio) we may look upon the number of lines counted as though they were the actual powers of the microscope, and proceed at once to apply the formula, thus obtaining results which correspond precisely with those given by the more lengthy process.

An example may be useful:—

Magnifying power with the tube closed, - -	100
Magnifying power with the tube extended three inches, - - - - - - - -	150
Increase, - - - - - - -	50

Therefore, $\frac{100 \times 3}{50} = 6$ (inches), optical tube-length.

Again by the shorter way:—

Number of lines that fill the field with the tube closed, - - - - - - -	30
Number of lines that fill the field with the tube extended 3 inches, - - - - -	20
Increase, - - - - - - -	10

Therefore, inverting these, $\frac{20 \times 3}{10} = 6$ (inches), optical tube-length.

An objective well corrected for central light is not necessarily well corrected for oblique light, and *vice versa.* This is especially noticeable with the best, wide-angled, dry objectives, although it holds true with the best of any kind, although probably not to the same extent as with the widest angled dry lenses. Certain immersion-fluids also demand a different adjustment of the objective with central and with oblique light, and again *vice versa*, all these delicate little points in the manipulation of his best tools being the task which the earnest microscopist must teach himself by observation and by experience.

A change of eye-pieces will likewise call for another adjustment of the objective. Taking out the two-inch, or A, ocular and dropping in the B, or higher-power eye-piece, will make a change for the worse in the image obtained with the best objective. And in this case, to bring back the perfection so much prized by the accomplished manipulator, will call for a movement of the adjustment-collar further toward the open point, or zero, the reason being that with the shorter (higher-power) oculars the optical tube-length is increased, the effect being similar to that obtainable by the use of a

cover-glass thinner than that for which a non-adjustable objective has been corrected, and calling for the extension of the draw-tube, or for an adjustment of the collar further toward the open point. A return to the use of the lower-power eye-piece will again produce a deterioration in the image, and will call for the shortening of the draw-tube, or the replacing of the adjustment-collar at the point toward "closed" at which it was before the higher-power ocular was employed.

This holds true with the ordinary Huyghenian oculars, but with the compensating eye-pieces as made by Zeiss, the microscopist is relieved of this necessity since these splendid optical tools are so constructed that the focal plane is at the same place in each, the image being formed in the same relative position with them all. This, aside from the improvement which they produce with even the ordinary high-power objectives, is another argument for their use; but the reader should remember that, while the ordinary achromatic objecttives are improved in performance by the use of Zeiss's compensating eye-pieces, it is only the high powers that are so improved. The lower powers are affected for the worse. It is therefore to the advantage of the microscopist that wishes to work with high and low powers, to have within his reach both kinds of eye-pieces, provided he desires to get the best images which all his objectives are capable of producing.

While the compensating oculars of Abbe and Ziess were designed primarily to cancel the slight amount of chromatic aberration remaining in the apochromatic objectives, the permanent position of their focal plane was a secondary consideration, but an exceedingly useful one, as by their employment a change in the focus of the optical combination is rendered unnecessary.

When a higher-power compensating eye-piece is substituted for a lower power, no change is necessary in the position of the objective's collar-adjustment.

Some time ago Mr. Edward Pennock, an accomplished theoretical optician and expert manipulator of objectives, suggested the construction of a series of oculars that should have one of the good qualities possessed by the compensating, although imitation was not thought of, my impression being that these special "parfocal" oculars were suggested and made before the compensating eye-pieces were put in the market.

The Latin name, parfocal or equal focus, explains the special quality of these productions, the one in which they resemble the compensating. Such oculars are made by Messrs. Queen & Co., of Philadelphia, and by the Bausch & Lomb Optical Co., of Rochester, N. Y. It would be an improvement if all opticians would adopt the principle, as the microscopist would then gain an important convenience, and as they do not require a different collar-adjustment of the objective with a change from one magnifying power to another, the advantage would be great indeed.

I have never had the pleasure of examining parfocal eye-pieces with this subject of collar-adjustment in mind, but I am assured by Mr. Edward Pennock that no re-adjustment should be required, and by the Bausch & Lomb Optical Company that with their eye-pieces "when substituting a high power for a low power, it is not necessary to change the collar-correction of the objective; a slight turn of the micrometer-screw (fine-adjustment screw) is all that is necessary."

Thus the microscopist that has the privilege of using the parfocal oculars, and has carefully adjusted his objective under another power than that which he desires

finally to use, may make the change with impunity, feeling sure that if the correction has been carefully made, he is losing nothing in the good performance of the lens, although he may not have exercised his eye over the performance of the objective with that special power of ocular. This is an exceedingly great advantage in favor of the parfocals, and one that should bring them into more general use.

There are few exercises in the educating of the microscopist's eye better adapted to teach him how to obtain the best which his objective can give, than this experimenting with the effect on the position of the adjustment-collar after a change of Huyghenian eyepieces over wide-angled objectives. An eye sensitive to the usually slight deterioration in the image may be considered a valuable possession by its owner, since with it he will be able to distinguish smaller objects and finer details, than will the microscopist that has neglected to teach himself this accomplishment, and to train his eye to be the valuable servant it should be, and which it will be if its responsible owner will do his part.

Balsam-mounted diatoms are of course the best objects over which to make the experiments, and the secondary structure of those diatoms is perhaps the most valuable object which may be used as the test. Even with the best of wide-angled objectives it is no light task to see distinctly a fracture passing through this minute secondary structure, yet it can be done, after the necessary preliminary eye-training, a training which will amply repay, in future service, the outlay of time, patience and labor demanded in its attainment. If the microscopist is to enter into the serious investigation of any natural object, either for his amusement

only or for the instruction of his fellows, he should consider the time well spent which he uses in the most careful study of the action of his objectives with various immersion-fluids, and under various eye-pieces, and with as many kinds of secondary diatom-structure as he may be able to obtain. The more acute the eye becomes in this work, for it is work of the most delicate character, the surer he may be that he is getting the best out of his objectives when he comes to use them over an object about whose structure he is ignorant, and the surer too that he is getting a true image.

To the diatoms the world owes a debt of gratitude which it can never pay, for it is to the study of them that is due in great part the immense advances made in the construction of the modern objective, and to this the world owes more than perhaps it knows. To supply the amateur microscopist with the objectives that he has demanded so that he may be able to see a few more striæ on a certain diatom, or to see them better, the optician has exerted himself to apply all his optical knowledge and to seek more, so that he may respond to the demands coming primarily from the diatom but through the amateur microscopist. Without the amateur microscopist and his efforts to have his objectives so improved that he might the better resolve his little diatom, the microscopical world would never have had the immersion-objective of the present day, and the great world of medical science would never have known of the cholera spirillum nor of the *Bacillus tuberculosis*.

It is not too much to predict that within only a few years the cholera will have become a disease unknown except as it is remembered by the aged physician, or is recorded in the books. Having learned the micro-

scopic cause, the scientific man will before long be able to overcome it, and to stamp out of existance the terrible disease which it has provoked. If the microscope had never done anything more than this it would deserve an immortal fame. But it has done more, and will do still more in the future as the amateur microscopist shall continue, as he will continue, to stimulate the opticians to renewed efforts to give the advanced worker new and better tools with which to prosecute his investigations. Without the amateur, the microscope of to-day would be only a dream of the future; without the diatom and the fussing of the amateur over the striations of that diatom, the microscopical world would still be lingering near the edge of the dark ages, and histological and hygienic science would yet be in their swaddling clothes.

But the diatom and its good work have not yet been exhausted. It is only within a short time that the microscopist has suspected that it has a secondary structure a thousand times more delicate than are the striæ over which he has labored so long and so hard; and it is still more recently that he has suspected, from the little that he has thus far been able to see, that there is within the secondary a tertiary structure, after which he is to strive, and for which the optician should begin to prepare himself. And all this reacts for the better, and brings about the "higher criticism" in the best sense, for while the scientific world is yet tempted to smile at the enthusiasm of the amateur microscopist it never refuses to take advantage of what that amateur offers.

The microscopist then that trains his eye, and studies the action of his objective under various conditions, is not wasting his time. The more he can see of the inexhaustable microscopic world and the better he can

see it, the happier will he himself be, the better informed will be his successor and the better prepared to take up the work when his predecessor shall have fallen on sleep.

To ascertain the initial power of the objective, that is, the power without the eye-piece, make the body-tube about ten inches long from the back lens, focus the microscope on a stage-micrometer ruled to hundredths of an inch for use with powers up to the one-fourth or the one-fifth, to thousandths of an inch for higher powers, and place the instrument in a horizontal position. Remove the ocular, and over the body-tube fasten a piece of translucent paper, or a slip of finely-ground glass, and if necessary re-focus until the micrometer-lines are distinctly seen on the paper when strong light is reflected up the tube. It is usually necessary to use direct sunlight, although strong lamp-light will sometimes answer the purpose. Mark the lines on the paper, and measure the spaces with a rule divided to tenths of an inch. If the micrometer one-hundredth inch spaces become one-tenth inch on the paper, the amplification is represented by ten; if five-tenths, fifty, each tenth representing an amplification of ten. If the one-thousandth inch spaces on the micrometer are used with high-powers, as they must be, and this space becomes on the paper one-tenth inch, then each tenth will represent an amplification of one hundred.

Mr. E. M. Nelson has suggested another method which may be more accurate, but which is scarcely as convenient. He describes it as follows:

In practically measuring the power, it will be found a more accurate plan to increase the distance [that is, from the objective to a screen, or to the paper on the end of the draw-tube], to, say, 60 inches, and to di-

vide the result by six. These measurements are very easily performed when one has a camera, but it is not so easy to do them without. Therefore, another and somewhat loose way of getting at the initial power, that is, the power of the objective alone, is as follows: Measure the combined magnifying power of the objective and, say, the two-inch, or *A*, eye-piece, and divide the result by 5. This method would do very well if the multiplying power of the eye-piece was 5, and if the length of the body remained constant. As it is not an easy matter to find out the exact multiplying power of an eye-piece, Mr. Nelson recommends any one desirous of knowing this to measure, or to get measured, the initial power of one of his objectives; then measure the combined power of this lens and the eye-piece, paying great attention to the tube-length during the operation. This will give him once for all the multiplying power of his eye-piece with that tube-length. He will then be in a position to ascertain the initial power of any other lens with that eye-piece and the same tube-length. But as the optical tube-length may differ from the actual tube-length, and does differ to a certain extent with objectives of ordinary construction, the process is not so simple as it seems. In order to get fairly accurate results with the higher powers, a certain percentage must be deducted. To give some examples:—

Thus the one-inch objective at 60 inches from a screen increases the image of 0.01 inch to 0.66 inch, its power therefore is 66, which at 10 inches becomes 11, or the initial power. The combined power of this lens with the A eye-piece is 55, which gives 5 as the multiplying power of the eye-piece. Now if the combined power of this eye-piece with a ⅔ inch objective is 75, we may assume that the initial power of the ⅔ is 15.

If however, we treat higher powers in the same way, we shall get too high values. Thus the combined power of a ¼ and the eye-piece is 203; dividing by 5 we get 40.6 as the initial power whereas 39.3 is the real power.

Again, the combined power of a certain $\frac{1}{12}$ and the eye-piece is 600, which divided by 5 gives 120 as the initial power, whereas it is in reality 113.2. The empirical rule employed by Mr. Nelson is to deduct 2 per cent. for the ½ inch objective; 3 per cent. for the ¼; 4 per cent. for the $\frac{1}{6}$; 6 per cent. for the $\frac{1}{8}$, the $\frac{1}{12}$, etc. Thus, taking the ¼ mentioned and deducting 3 per cent. from the 203 we get 197, which divided by 5 gives 39.4, a result very near the truth.

A certain $\frac{1}{8}$ gives a combined power of 450; deduct 6 per cent. and we have 423; dividing by 5 gives 84.6, the actual power being 85. For short bodies of 6⅓ inches in length, or the Continental size, a different percentage must be employed. The following gives fair results: 2 per cent for ½; 4 per cent for ¼; 6 per cent for $\frac{1}{6}$, 8 per cent for $\frac{1}{8}$; and 10 per cent for $\frac{1}{12}$.

In reference again to magnifying power, Mr. E. M. Nelson says in another and more recent paper, that the limit of combined power for best definition may be found for any objective of any given aperture, by multiplying its N. A. by 400, stating as an example, that the limit of power for best definition with a ⅔ inch of 0.3 N. A. is 120 diameters.

If, in this case, the ⅔ inch is truly named it will have the initial power of 15 diameters. To acertain the highest powers that may be applied in the eye-piece to be used, divide the 120 diameters by the 15 and the result, 8, will be the required amplifying power of the occular needed to work the objective up to its limit of

good definition, according to Mr. Nelson's theory, which is doubtless correct.

To Measure the Focal Length of an Objective.

To ascertain this for an objective whose box or mounting has not been marked by the maker, a rare occurrence, or when it is suspected to be incorrectly named or under-rated, a method is to multiply the tube-length by the quotient obtained by dividing the diameter of the object by that of the image. If F is focal length, t the tube-length, D the diameter of the image, and d that of the object, the formula will be, $F=(\frac{d}{D})t$; and if the stage-micrometer is ruled to hundredths of an inch, the body-tube ten inches long, and one micrometer-space used as the object becomes five tenths inch on the paper at the top of the tube, then $F=(\frac{0.01}{0.5})10$ or $\frac{1}{5}$ inch.

High Magnifying Power.

The highest-power objectives ever made are a one-seventy-fifth by the late R. B. Tolles, of Boston, and a one-eightieth by Powell and Lealand, of London. The immense amplification obtainable by such objectives is chiefly a curiosity. It has been said that anything more miserable than the one-seventy-fifth need not be desired, a statement that I can readily believe. No discoveries have ever been reported as having been made with it, so far as I know, and few observations have been described. In reference to the Powell and Lealand one-eightieth I have heard nothing.

The use of such objectives calls for the highest skill of the microscopist, and to see anything with them demands more than ingenuity. No cover-glass can be had thin enough to allow the $\frac{1}{75}$ to act through it; mica films are necessary.

A mistake often made by the amateur is to use too high a magnifying power. Mere size in the image is not a necessary nor even a useful feature. It is rather a detriment. The microscopist should use the lowest magnifying power compatable with distinctness of the image, and with the requisite separation of minute and contiguous parts. The image is best when it is clear and vivid, rather than huge and foggy. It is separation of closely contiguous parts, not the magnitude of those parts, that the eye needs and appreciates.

It is probable that 2,000 diameters represent the limit of useful amplification. Very much more has been used but not with praiseworthy results.

Immersion-objectives.

Immersion-objectives are those that require a drop of liquid between the front lens and the cover-glass when in use. Among the advantages obtainable by their employment are increase of working-distance and increase of numerical aperture, with, as a consequence, the admission of more light, and especially the partial, or in some cases, the complete extinguishment of the cover-glass, by which its aberrations are obviated and two reflecting surfaces, those of the cover and of the front lens, are cancelled. The honor of discovering the principle is usually conceded to the renowned Italian professor, G. B. Amici, who exhibited water-immersion objectives at Paris in 1855. It is also said that he used oil as well as water for the immersion-medium, and that he therefore deserves the credit for originating oil-immersion objectives. For the modern homogeneous-immersion, however, we are indebted to Mr. J. W. Stevenson, a well-known British microscopist. It was he who suggested to Professor Abbe and to Dr. Zeiss that they should turn their attention to the theoretical and the practical application of the principle; it is to him, therefore, that we owe this great modern advance in practical microscopy.

The use of immersion-objectives is attended by a little more inconvenience than that of dry objectives, and the immersion fluid is likely to be carried over the edge of the cover by the movements of the stage, and so is liable to mingle with the mounting medium in those preparations which are not permanently sealed. This annoyance may be avoided to a great extent by using square covers somewhat larger than the cement ring enclosing the object, the movements of the stage then bringing the ring indistinctly into view, and the pro-

jecting borders of the square protecting both the immersion-fluid above it, and the object beneath.

The front lens of these objectives must also be carefully cleaned and dried after the immersion-fluid has been as carefully applied. But the advantages obtainable more than counterbalance the inconveniences.

The fluid is always applied between the lens and the cover-glass. It is difficult to imagine any human being endowed with such unmitigated stupidity, that he should pour the immersion-liquid into the tube of the lens-mounting, yet instances of the kind have been reported.

It is recommended by some that the water, glycerine, oil or other fluid be applied in a small drop to the cover, and the objective racked down until the front lens comes in contact with it. The only advantage of this method, and that advantage is very slight, is that by it the probability of disarranging the object by the pressure of the thick liquid compressed between the cover and the lens, is lessened; and the reader may prefer this method, especially when using glycerine-immersion or homogeneous-immersion objectives, but a great disadvantage is that the moment the objective touches the liquid, the microscopist loses the power to appreciate the distance between the lens and the cover, and is therefore likely to rack down too far and so to do some damage, or not far enough and thus leave too much to be done by the fine-adjustment screw.

When using glycerine or homogeneous-fluid, I am in the habit of applying a drop to the front lens of the objective instead of to the cover-glass. This may be done by means of the cork from the bottle of fluid, a drop being allowed to form at one edge, whence it is carefully placed on the objective without touching the cork to the lens-front; or a rod may be forced through the

cork and the drop adhering to this applied to the lens. One leg of a rubber hair-pin forced through the cork is useful for the purpose, as none of the chemical liquids used for immersion purposes will act on it, as some of them will act on a metal wire. When the drop has been applied to the front of the lens, the objective is attached to the body-tube and racked down until the fluid touches the cover; and as the microscopist looks across the slide, between the cover and the lens, the objective is still further lowered while the lessening distance and the expansion of the fluid are watched, the expansion being continued until the objective is supposed to be approximately focussed, when the fine-adjustment focusses it upward or downward to the proper point. These movements demand exceedingly great delibera-tion and caution; deliberation so that the object may not be disarranged by the slow expansion of the thick immersion-fluid, if it is not permanently mounted, and caution that the objective be not injured, for immersion lenses are easily disordered. Their lenses are larger than those of smaller angled dry objectives, their construction is more delicate, and they must be treated with more care.

When a water-immersion is to be used, that is, an objective with which water is the immersion liquid, I am accustomed to focus it as a dry objective, as may easily be done, although the definition will probably be abominable and the field dimly lighted, yet enough may be seen to show that the desired object is in view. With a camel's-hair brush a drop of water is then added to the cover near the edge of the objective, under which it will run by capillary attraction. Here all danger of forcing the object out of position or of injuring the objective or the cover, is with ordinary caution, reduced to nothing.

To clean the front of a water-immersion, after using it, the careful employment of the Japanese filter-paper is all that is needed. To remove the glycerine when used by itself or in combination with a salt, as in the homogeneous-immersion fluids, I am accustomed to wipe away the greater portion with the Japanese paper, and to remove the rest with a few touches of the tongue, finishing with the dry paper.

The cedar-oil used with homogeneous-immersion lenses is thickened with dammar, so that a touch of the moist tongue is likely to cause a deposit of some of the gum on the lens, and to necessitate repeated applications of the paper moistened with alcohol to remove it.* It is better with this liquid to employ the paper alone, and to finish with another piece moistened with alcohol, and to wipe the lens dry and perfectly clean with still another piece.

It is always well to clean an immersion-objective as soon as possible after using it. I have known instances in which the front lens was so insecurely burnished into the metal cell that the fluid has penetrated to the back of the glass, and made necessary a journey to the manufacturer. When the objective is to be out of use for only a short time, it should be placed on the table with the glass surface upward, and when the evening's work is finished, it should be carefully returned to its brass box, after a scrupulously neat cleaning.

When about to measure the angular aperture of an immersion-objective the front must of course be immersed in the proper medium. This may be done by applying a thin cover-glass to the front lens by means of a drop of its special fluid. It is better however, to estimate the numerical aperture by the method already described.

* Since this was written I have received from the Bausch & Lomb Optical Company, a supply of cedar-oil not open to this objection.

To Measure the Refractive Index of the Immersion-fluid.

The kinds of homogeneous-immersion media are numerous, the object of all being to reach a refractive index as nearly as possible that of the front lens of the objective. The basis is generally pure glycerine in which is dissolved, usually by the aid of heat, various chemical salts, among which are chloral hydrate, zinc sulpho-carbolate, cadmium chloride, zinc iodide, distilled zinc-chloride, and perhaps others. The microscopist himself may prepare any of these fluids, but he would better buy them of the optician that makes his objectives. He will thus not only save himself trouble, but he will be sure that the index of the fluid will be as nearly correct as may be. Upon the proper condition of the immersion-fluid depends the proper action of the objective, the best performance of the best lenses being defeated by a liquid that is not of the correct refractive index.

In any event it is important that the medium should have a refractive index as nearly like that of liquid crown-glass as possible, and for the purpose of learning its condition in this respect, several devices have been suggested. With his cedar-oil, Zeiss sends out a bottle with flattened sides, to the stopper of which is attached a glass wedge which is to be immersed in the medium and held against the light, when certain appearances in a distant object will show when the correct refractive index has been attained. Not long ago Prof. Hamilton

L. Smith, the well-known American microscopist, devised a little instrument which is more convenient and more accurate than Zeiss's. It is shown in Fig. 11, and is described by its inventor as follows.

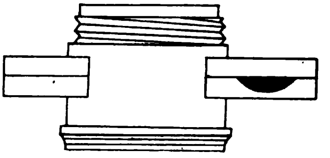


Fig. 11. H. L. Smith's test-slide for refractive index.

It consists of a brass adapter with the society screw above it to attach it to the body-tube of the microscope, and one below it to receive an objective, the one-inch being generally used with it. Through openings in the sides two glass slips are inserted, one having a polished cavity near the end. These slips are of crown-glass with a refractive index as nearly as possible that of the cover-glass. To test the medium, a drop is put in the concavity, the slips placed together, and inserted in the adapter above the objective. The medium passes between the two by capillary attraction, and the microscope is focussed on an object, the microscopist looking through the slips and the interposed medium. The focus will not differ with or without the glass slips, and when the concavity is pushed directly over the objective, if the medium be optically homogeneous with the slips, the focus will need no change and the definition will be unimpaired. But if the medium has not the proper index, while the focus may need no alteration, the outlines of the object will be surrounded with colored fringes.

If the focus has been obtained by means of the rack and pinion, the fine-adjustment always remaining the same, one can readily ascertain, in the following way, the refractive indices of the various media proposed for use with immersion-objectives. Let a mark be placed

on the rack-bar or on the sliding draw-tube, as the case may be, when the focus is obtained with the glass slips in the position shown in the figure (Fig. 11); this mark will indicate, for example, a refractive index of 1.52, or that of crown-glass. Filling the concave now with cinnamon-oil, and focussing again (using the same objective and eye-piece), we get another position for a mark indicating a refractive index of 1.6, the index of cinnamon-oil. Using water we get still another, 1.33; and glycerine 1.41; the extremes will be about half an inch apart, as measured by the bar or by the tube, and by interpolation, we can thus get pretty nearly the refractive index of any fluid medium. Prof. Smith reports that he has found the so-called homogeneous media sold in the shops to differ very greatly, fully one-fourth of an inch out of the way in many cases.

When one has a fine objective and with a certain immersion-fluid has obtained certain positions of the adjustment-collar for the best work on certain tests, the exact refractive index of the medium can be ascertained by this instrument, and afterwards always secured. A non-adjustable immersion-objective, a one-eighth by Spencer, performed most admirably, both with oblique and with direct light, using the medium furnished by the maker, but showed indifferently well with another medium which, on being tested with this little apparatus, required an alteration of focus necessary to obtain distinct vision, or rather the most distinct vision, of fully one-fourth of an inch. On diluting the second medium to bring it to the same index as that sent out by the maker, the performance was entirely satisfactory. It will be understood that there should be a diaphragm in the adapter of such a size that it shall prevent the passing of any light except

what actually passes through the fluid when the concavity containing the immersion-fluid to be tested, is put over the objective.

To Focus an Objective.

This has already been incidentally referred to, but it may well be repeated, as among his first lessons the amateur or the novice should learn how to focus his objectives properly, every one of which, it does not matter whether it be a five-inch or a one-fiftieth inch, should without exception be focussed in the same way. Sometimes there are two ways of doing the same thing. Here there is but one. It is this: In no circumstances should the objective be focussed by racking the body-tube down while the microscopist is looking through the instrument. Always look across the objective, between the front lens and the cover-glass, or the slide, while the body-tube is carefully racked downward until the front of the high-power objective is almost in contact with the cover; then, while the eye is at the eyepiece, rack the body upward until the focus is approximately obtained, finishing with the fine-adjustment. Proceed in this way always, and at all times, and in all circumstances, even though it should be necessary to place your ear flat on the table-top whilst you look across the objective-front toward the light, and it will be

to the amateur's advantage. It will be especially advantageous to the novice, if he will from the very first, cultivate the habit of racking the body-tube upward whenever the slide is to be taken from the stage. This good habit will soon become automatic, and if both these rules be observed, there will be no danger of breaking or of scratching the soft glass forming the front lens of the objective, nor of injuring the slide. The latter might not be of any importance, whereas the breaking of an objective is a disaster that cannot be remedied.

The Maltwood Finder and Similar Devices.

Reference has already been made to the difficulty of finding a small object, or some special part of a larger object, with a high-power unless a mechanical stage be used. The field of the high-power objective is so small that the chances of bringing the desired object within its circumference are slight. Usually it is necessary to substitute a low-power lens, bring the specimen within its field, then to re-attach the higher-power objective, in or near whose field the object should be.

On mechanical stages there are commonly engraved two sets of lines about one one-hundredth inch apart, the scales resembling those of a micrometer. These are intended to facilitate the finding of the object the second time, the objective being noted, and the position of the stage recorded as read from the horizontal and the vertical scales on its surface. When the stage

is again placed in those positions, the same objective used, and the slide laid on the object-carrier as it was before, the object should then be in the field.

Several devices have been suggested for the convenience of those microscopists that do not possess a mechanical stage. These consist of lines photographed or ruled on a glass slip, their number usually being great and the spaces between them small, each of the latter bearing one or more figures. The best known of these finders is Maltwood's, a glass plate bearing twenty-five hundred squares, so numbered that the position of an object may be recorded by recording the numbers within the space over which it may be when in the field of a certain objective.

The object is brought into the centre of the field of view, when the slide is removed and the Maltwood finder substituted. The numbers on the square now occupying the position previously occupied by the object are noted, and whenever this special square is again brought into the field of that objective, the stage will be in a position to bring at once the desired object into that field.

The Condenser.

The sub-stage condenser is the most important accessory that the microscopist can have, especially if he intends to work with first-class, wide-angled objectives. Its purpose is to supply a wide and solid cone of light,

not primarily to illuminate the object, but to give the very light of life to the objective itself. Without a modern, wide-angled condenser the microscopist is badly handicapped, although he may possess the best objectives to be had for money. The condenser brings out the good points of the lenses in a surprising way, and it also reveals with as painful distinctness, the bad qualities of the same lenses.

The microscopist should purchase the best condenser he can find at the opticians', and attach it permanently to his stand. It may be used to increase the illumination until the eye refuses to endure it, or the light, by its means, may be reduced to the faintest glimmer. By its means again, if it have the proper angular aperture, the whole aperture of the objective may be filled by a solid cone of rays; and by the use of the proper diaphragms, or by moving the entire condenser laterally, illumination of the greatest obliquity may be obtained for the resolving of tests, or for the study of obscure structures of a certain character.

The defining and the resolving powers of the objective are improved by its use; indeed, the best, highest-power, homogeneous-immersion lenses will not do themselves even partial justice without the use of wide-angled condensers now fortunately becoming common.

The apparatus is a combination of two or more lenses forming an instrument not unlike a greatly enlarged objective. It is fitted to the sub-stage ring so that it may be accurately centred, a condition absolutely essential to its best performance, and so that it may be moved upward or downward to bring the light from the mirror to a focus on the object, or to remove it beyond the focus so as to reduce the intensity of the illumination, although this method of using it is

not to be unreservedly commended with wide-angled, high-power objectives of the present day. Some method, however, of changing its position vertically, either by rack and pinion or by direct finger-movements, is absolutely necessary.

It is always accompanied with diaphragms to reduce the size of the illuminating cone, to obtain light of great obliquity or black-ground illumination. In the best condensers these diaphragms are applied below the lenses, and this should always be their position. In no circumstances should they be above the front lens of the apparatus.

Authorities on the subject recommend that the condenser should never be used without being accurately focussed. Dr. W. H. Dallinger says that it should always be racked upward until, when the microscopist looks down the body-tube after the eye-piece has been removed, the back lens of the objective is three-fourths full of light. M. H. Peragallo, in the "Annales de Micrographie," gives an elaborate discussion of the theoretical principles involved in microscopical illumination, and states that the back lens of the objective should be only one-third filled with light. Dr. Dallinger's teaching calls for more (three-fourths), and the microscopist that attempts to use his objective thus illuminated will have an experience that will teach him that, in ordinary circumstances, the method is impracticable. According to Dr. Dallinger's contention, which is here correct, if the condenser, after having been focussed, be racked a little further upward while the microscopist is still looking at the back lens of the objective, there will soon appear on each side of the illuminated disk a little dark spot showing that the apparatus has been raised too high, and is within the

focus, as the late Dr. W. H. Carpenter wrongly advised the microscopist to use it. The proper position, according to Dr. Dallinger, is said to be that reached just before the dark spots appear; that is, the condenser is then focussed.

This is undoubtedly the proper way in which to use the apparatus, but it is an utter impossibility so to use it, unless the microscopist have some way of reducing the terrible intensity of light which will then pour into his eye. This reduction is to be obtained, not by racking the condenser downward, or beyond the focus, which would be using it, as well as the objective, at a disadvantage if the objective is a first-class lens, but by the employment of properly colored glass to be placed between the lamp and the mirror, or between the mirror and the condenser, the correct color being double cobalt-blue, a kind of glass not to be had in this country, and until recently scarce even in Europe. From this Dr. Dallinger recommends that screens be made and placed between the mirror and the source of light, so to modify the illumination that the eye may endure it. Or two disks of this special glass may be prepared and inserted in the sub-stage below the condenser, with the same purpose in view.

If used as M. Peragallo recommends, the condenser must also be supplied with the blue glass to modify the illumination, although the advanced microscopist may be able to endure the unmodified light, since his eye has, by practice, become less sensitive to such impressions while it has also become better able to appreciate minute points, delicate details and sharply defined outlines. But while it may be possible or necessary to use only one-third of the back lens, or even less, doing so would not be working the objective, nor the

condenser, up to the best, if condenser and objective are first-class. With the French microscopist's method we should be losing in two particulars, yet while his recommendation may be put into practice, Dr. Dallinger's can not, unless the right kind of blue glass can be obtained to reduce the terrible intensity of the illumination from the modern, wide-angled condenser. But the only way in which, at present, the teaching of the expert British authorities can be followed is to send to Messrs. Powell and Lealand, the well-known opticians of London, and import the blue glass, as they are the only dealers who, so far as I know, supply the material proper for the purpose.

It is indeed possible to use a wide-angled condenser when almost in focus, if we employ a blue glass chimney to the microscope-lamp, and put below the condenser three thicknesses of the blue glass as supplied with the "Acme lamp," by Messrs. Queen & Co., and by Messrs. James Stratton & Son with their "Stratton Illuminator." By this means a one-tenth inch objective, or higher power, may be used with the condenser accurately focussed; but with the one-fifth or with lower powers the light must still be modified by racking the condenser downward, or preferably by using diaphragms. The unprotected eye can not endure the intensity of the light under these conditions, and if more blue glass be inserted into the sub-stage, the illumination becomes too much weakened, and the image is deteriorated.

That the condenser will give us its best service when carefully focussed under our first-class objectives, there can be no doubt; and if the American microscopist can modify the light without depriving it of any of its good qualities, he should always use the accessory in that

position. But I fear he will not be able to do so with all objectives, unless the opticians come to his help, as Messrs. Powell & Lealand seem to have come to the help of the British microscopists, and give him the right kind of blue glass. But in the present circumstances, the advantages of using the condenser when accurately focussed are so great, that it seems best to keep it in focus and to reduce the intensity of the illumination by diaphragms. This will reduce the angle of the illuminating cone, which is not always a commendable thing to do, but at present is apparently unavoidable. To get the greatest benefit to be obtained from a condenser, the object should be exactly at the apex of the illuminating cone issuing from the front lens of the apparatus.

The microscopist may be certain that the condenser is focussed even while looking through the instrument, and without removing the eye-piece to gaze down the body-tube. To do this, the condenser, after the objective has been focussed, is gently racked upward, while the eye is at the ocular, and the ascent continued until the dust-particles on its front lens are visible in the field as blue or blue-bordered objects which are rather indistinct yet plainly visible. These dust-particles are sometimes so conspicuous that they become menacing annoyances in observations with high-powers, and the front lens of the condenser must be dusted with a camel's-hair brush, or racked slightly below the focus. It will also sometimes happen that when the apparatus is used with low powers, or when it is occasionally racked far downward, that dust-particles and finger-marks on the blue-glass in the sub-stage will become apparent, and may possibly mislead the observer into thinking that the instrument is in its proper position.

The widest-angled condensers for use with the widest-angled homogeneous-immersion objectives, are so made that they may be employed in immersion contact with the lower surface of the slide. A drop of glycerine or of homogeneous-immersion fluid is placed on the upper surface of the condenser and brought into contact with the lower surface of the slide. Such immersion-condensers must necessarily be used in focus; and with them the intensity must be in some way decreased, since the normal eye can not endure it when unmodified.

There are two forms of the accessory in the optical market, one with no corrections for the spherical and chromatic aberrations, the other carefully corrected for both of these troublesome things. The most popular form is Abbe's, and belongs amongst the uncorrected, although in recent years its accomplished inventor has issued a corrected condenser which he recommends for use in microscopical photography. It is also commendable for ordinary, every-day use, as the uncorrected form adds an immense amount of spherical aberration for the objective to contend against, so that diaphragms should always be used with it to cut off some of the uncorrected marginal rays.

In reference to the uncorrected accessory Prof. Abbe says: "The condenser is not made achromatic for the reason that, for the effect contemplated, it would be altogether useless to seek to obtain a sharp image of the cloud or other source of light, as it is in like manner quite immaterial whether the image is formed precisely on a level with the object, or somewhat above or below it." Several British microscopists take issue with Prof. Abbe on these points, and insist that the condenser should be corrected; and as Prof. Abbe has re-

cently made a corrected form of his own celebrated apparatus, it would seem that he has changed his opinion.

Messrs. Powell and Lealand, of London, make an oil-immersion condenser of wide angle and a high price; Watson and Son, also of London, make an excellent condenser which is corrected, its angle being 1.0 N. A. against 1.40 of the Powell and Lealand form. In this country, Messrs. Bausch and Lomb, of Rochester, N. Y., make an achromatic form of the Abbe condenser, as well as another which is not corrected.

Low-power objectives, those, for instance, below the one-fourth or one-fifth inch, and those of small angular-aperture, do not call for the use of the condenser. Sufficient illumination, generally more than is needed, may be had with these from the concave mirror alone. It is also possible to use an objective of low-power as a condenser, if the sub-stage ring is supplied, as it should be, with an adapter carrying the society screw. The objective, when used for this purpose, is screwed into the adapter with the front lens facing upward, the light being reflected through it from the plane mirror. If a microscopical lamp be used, or a bull's-eye lens be interposed between the lamp and the mirror, the plane mirror should also be used.

Several diaphragms, which are used below the posterior lens, for central, oblique and black-ground illumination, accompany all forms, or should do so. Those for central light have a central opening, the size of the cone of light and the obliquity of its lateral rays varying with the size of the diaphragm-opening employed. For oblique illumination two lune-shaped diaphragms are usually supplied. These are placed in the diaphragm-carrier, one at a time, of course, in any posi-

tion that may be needed to produce the effects desired; in some the diaphragm-carrier may be rotated. For black-ground illumination those with the central disk supported by radiating arms are used, but to obtain the effect with wide-angled objectives something more is needed than the use of these special disks. A circular diaphragm must also be placed at the back of the objective.

The diaphragm-carrier in the American forms of the condenser is usually a sliding plate into whose aperture the various diaphragms or stops are placed, when it is pushed below the lenses until a spring catch indicates that it is properly centred to the condenser; but this has nothing to do with the centring of the condenser to the objective.

For oblique illumination, the lunate disks are used, the larger when the greater portion of the cone of light is to be intercepted, the smaller when more of the rays nearer the centre are desired. With either size the condenser will give light of greater obliquity than many objectives will receive. The object, however, may be obliquely illuminated with rays from any direction, either by withdrawing the carrier and inserting the lune-shaped diaphragm in another position, or by rotating it, so that the light shall sweep around a circular course. This requires delicate manipulation, an objective of the proper angular aperture to receive light of that obliquity, and very accurate centring of all the parts. It may be done, however, with fine effect in the resolution of lined objects, diatoms for instance, but if the microscopist owns the wide-angled apparatus, and this form of oblique light is to be employed with a dry objective, the front hemispherical lens of the condenser should be removed and the remainder of the

combination focussed on the object without a diaphragm. Then insert the lunate disk, and, if all is well, a glance down the body-tube, without the ocular, will show a small double-convex spot of light near one border of the back lens of the objective, with the diffraction spectra also, if they are specially looked for.

If the sub-stage has lateral movements, as it has on some first-class stands, oblique illumination with the circular diaphragm-openings may be obtained, but somewhat less effectually, by moving the entire condenser from side to side.

In what is called black-ground illumination the object appears to be self-luminous, gleaming with the vivid radiance of molten silver, seeming to rest softly on a back-ground of the blackest velvet. Living animals appear like creatures fashioned from moonbeams; minute particles shimmer and flash like silver stars; a little heap of colored sand-grains seems a little heap of rubies and diamonds from Sinbad the Sailor's Valley of Gems. And to obtain such exquisite pictures it is only necessary to obstruct the central beam of light by a circular, opaque disk, allowing the object to be illuminated by the light that comes to it from the periphery. No rays reach the objective directly. All must first enter the object and there be properly refracted or inflected, or after passing through the object, must be thrown back on it by reflection from the cover-glass, so that under the beating of those waves of light it shall appear to glow with a soft intensity indescribable. This effect may be obtained, sometimes better and more easily, by sub-stage apparatus especially intended for the purpose, rather than by any sub-stage condenser.

For black-ground illumination, the central disk-diaphragm must be used, and with the one-inch objective

brilliant effects may be produced, with the proper objects. To do this with the one-inch of 33° and the uncorrected Abbe condenser of 1.40 N. A., it is necessary to remove the front lens of the condenser, when the effect will be exceedingly fine. Here again if the bull's-eye lens is placed between the mirror and the source of light, the plane mirror is to be used; if the light is taken directly from the lamp-flame, the concave mirror is the proper one to be employed. Black-ground illumination may be obtained with powers of from five-hundred to six-hundred diameters, but according to my experience it is not praiseworthy.

With the Abbe form of the condenser, Zeiss supplies diaphragms to be applied to the back lens of his wide-angled objectives when black-ground illumination is desired with them, the proper disk-bearing plate being placed in the diaphragm-carrier, and immersion contact made with the lower surface of the slide. The difficulty with any but Zeiss's objectives is to prepare the diaphragms for the back lens. With his they are made of metal, to fit properly when dropped into the mounting, and the opening will then be central. But if the microscopist must cut them from paper, he need not expect to obtain the best results. The directions are to drop the diaphragms into the back of the wide-angled objective, and then the microscopist is left, by all opticians except Zeiss, to take care of himself. Yet it is of course impossible for any one optician to supply these little parts, since no two objectives by different makers, of even the same magnifying power, have the same sized mounting. The microscopist must depend upon himself, and he will speedily observe that when the aperture is reduced by a diaphragm at the back lens, the defining and resolving powers of the objective

suffer an injurious diminution. The experiment is worth making although no other result than this be obtained.

While black-ground illumination is beautiful, it has little scientific value. I do not know that any discovery, or even any observation of importance, has ever been made by its use. It will at times exhibit certain structural features in a conspicuous way, but only, I think, after they have been previously observed, for in most cases this peculiar lighting appears to make the structure obscure. It may render the contour lines more distinct, and develop the whole object in a glamour of brilliant beauty, but the microscopist, while he never disdains beauty, never makes it the object of his pursuit.

Although oblique illumination may be obtained by the lateral movement of the condenser, if the sub-stage arrangements will allow it, such use of the apparatus is not to be commended. It should, for ordinary work, when oblique light is never wanted, be used with central illumination, and the more perfectly centred it is the better. To accomplish this, proceed as was described in connection with the centring of the illuminating beam with the objective and the mirror. But it will sometimes happen that while the condenser appears to be centred when it is near the focus, that it will be greatly out of centre when racked downward. In such a common occurrence a slight change in the position of the mirror, or of the lamp, or perhaps of both, is all that will be needed to remedy matters.

It frequently happens that with even excellent objectives, that after they have been carefully adjusted, and the outlines of the image are as narrow and as black as they can be made, that a narrow line of bright light is

conspicuously visible around the free edges of the object. This external line of light has been said to be an evidence of improper adjustment, and that a second-rate objective is being used. The fact is, that such a bright marginal line is evidence that the objective is asking for more light to be given it in a wider cone of illumination. The bright line can be almost cancelled in the image formed by first-class objectives, and greatly diminished in those of inferior quality, by supplying a wider cone of rays. The experiment is an instructive one, and can be easily made by using the condenser in a way that needs no description.

Black-ground Illuminators.

This form of illumination as accomplished by the sub stage condenser is not entirely satisfactory, although the effect may be moderately well obtained by that accessory with low-power objectives. It may be better done with appliances specially designed for the purpose, all of which deflect the illuminating rays so that they pass beyond the objective without entering it directly.

The Paraboloid.

This consists of a solid parabola of glass whose sides are so curved that the rays of light which impinge upon them are internally reflected, so that they escape from the front at such an angle that they pass beyond the front of the objective. The anterior surface is concave, the back one flat, and passing through the longitudinal axis there is, in some forms, a movable stop formed of a flat disk at the summit of a stem. The appliance is fitted into the sub-stage ring, the light reflected from the plane mirror, and the instrument focussed on the object. It gives excellent black-ground illumination with magnifying powers up to the one-fourth inch objective. When the central stop is present it should be pushed up when the paraboloid is used with a high-power lens and depressed for a low-power.

It may be used as an immersion instrument, as suggested by an anonymous writer, who then places the microscope in a vertical position, and having greased the stem of the stop to prevent the water from running down by its side, the hollow is filled and brought into immersion contact with the under surface of the slide. "With the highest-power objective generally used with black-ground illumination, as a one-fourth of from 75° to 110°, the object seems no brighter than usual, but the field is free from the foggy, diffuse light otherwise present, and the object appears beautifully distinct upon a jet-black ground. Even a one-fifth or a one-eighth of 130° gives the same effect of a deep black back-ground and shows the object with good stereoscopic effect in Wenham's binocular. With objectives of 170°, the main effect is that of a dark background, though not so perfect as with the lower angles."

There is, however, an immersion paraboloid devised by Mr. Wenham for use with powers higher than the one-fourth. This is similar to the foregoing, but the front surface is flat and the more readily to receive the drop of immersion-fluid, and black-ground effects are said to be obtained with objectives of comparatively wide angular-aperture.

The Spot Lens.

This is a large hemispherical lens upon whose plane surface is a central opaque stop to intercept all the rays except those passing through the peripheral parts. It is attached in various ways to the sub-stage, so that it may be focussed on the object, which is illuminated by the reflection from the cover-glass. It cannot be satisfactorily used with objectives higher in power than the one-half inch. With daylight or with parallel rays obtained by a bull's-eye condenser, the plane mirror should be used with this apparatus.

The Woodward Prism.

For oblique illumination in the study of diatoms, test objects and other preparations where delicate details are to be made out, the Woodward prism is a useful and simple appliance consisting, as first suggested by Dr. J. J. Woodward, of a right-angled prism attached by immersion contact to the lower surface of the slide. The original device was for use with certain first-class objectives in connection with the study of their angular aperture, but the opticians have so modified it that it is is now a useful little thing under lenses of very moderate aperture.

The upper face of the prism receives a drop of glycerine and is then applied to the slide according to the way in which it has been mounted, different opticians adopting different methods. The simplest is to have the little prism without metal mounting of any kind, when it is to be attached bodily to the slide, the drop of immersion-fluid holding it in place. If it should slip out of position, as it probably will when the stand is inclined, a strip of paper pasted along the slide will hold it securely. The prism is usually about half an inch long and half that length in width, its small size making it somewhat troublesome to manipulate, unless it is mounted for attachment to the stage or to the sub-stage.

It should be accurately centred to the objective, and the lower edge placed as nearly vertical as possible when seen through a low-power. Then attach the higher power to be used, swing the mirror to one side, using the bull's-eye condenser or a microscope-lamp to obtain parallel rays, and illuminate the field. The best effects obtainable cannot be indicated here; the reader must seek for them by experimenting with the mirror, the prism and the light.

Ex-Gov. J. D. Cox, speaking of this little accessory says: It may be safely asserted that for whatever purpose the Wenham reflex illuminator is useful, the Woodward prism is superior; and we have no hesitation in predicting that it will eventually supersede the paraboloid for black-ground illumination with low-powers. Indeed there is hardly one of the elaborate and expensive sub-stage illuminators whose work cannot be better done by this amusingly simple accessory, which can be so cheaply made as to form part of every outfit for a 'Students's Microscope,' being in fact less costly than the very cheapest achromatic condenser furnished with an educational instrument.

The late Dr. Allen Y. Moore was in the habit of using the prism for the illumination of opaque objects under high-power objectives, by attaching it with a drop of glycerine between its broad side and the upper surface of the slide. To accomplish the effect sought the object must be mounted dry on the cover glass, a dry objective should be used and the cement ring made of Canada balsam or some other transparent material.

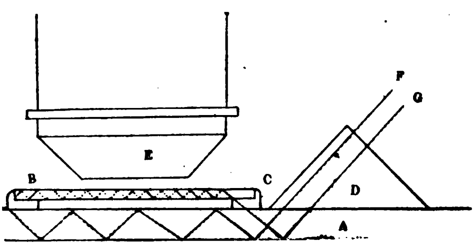


Fig 12. Illumination of opaque objects by the Woodward prism.

In the figure (Fig. 12), *E* is the objective, *B* the cover-glass, *C* the cement ring, *A* the slide, *D* the prism, and *F* and *G* two rays of light whose course is shown by

the dotted lines. The rays passing through the prism are reflected to and fro by the surfaces of the glass, brilliantly illuminating any transparent object that may be properly mounted there. Dr. Moore states that he has used this method with a magnifying power of four-thousand diameters, having plenty of light and good definition.

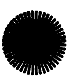
The Hemispherical Lens.

This is simply a solid hemisphere of glass attached by means of a drop of immersion-fluid on its plane surface to the lower aspect of the slide. It is used to concentrate on the object oblique light from the mirror when the latter is swung to one side. It may be prevented from slipping when the microscope is inclined, in the way suggested for the same purpose with the Woodward prism. A better method, however, is to use only a small amount of water, glycerine or whatever the immersion fluid may be.

Its optical action is such that the object is practically at the centre of a hemisphere, where the light is also brought to a focus, the lens being in effect extended by the immersion-fluid to include the slide and the object. It is used, as are so many of these illuminating accessories, in the resolving of diatoms or of other finely lined tests, and to assist the objective in the work. For other purposes it is of little or no importance.

Supra-stage Illuminators.

There are many pieces of apparatus for illumination from above the object, but, as with those for sub-stage use, the majority will be here omitted. Some have been forgotten and are not worth recalling. Others are so seldom used that they are rapidly on their way to oblivion, and are rarely seen anywhere except in the opticians' lists. Among these is the Lieberkuhn.



The Lieberkuhn.

This is a cup-shaped metal reflector, its inside surface polished so as to direct the light upon an opaque object after it has been attached to the objective, over which it is slipped by means of a collar. It was devised in 1738 by Johann Lieberkuhn, a German anatomist and microscopist for whom it is named. At one time it was extensively employed, but it has so many objectionable features that it has now fallen into disuse, although its effects are often admirable.

It must have a special focus and therefore a special curvature for every objective for which it is intended, and these are usually low-powers.

Each objective must therefore have its own Lieberkuhn. In using it, the light must be intercepted by a central opaque disk, or a dark-well, so that no rays shall reach the object directly, but pass around it to

the Lieberkuhn thence to be reflected downward. Consequently the object must not be too large. Intense surface-illumination may be obtained equally well, much better in some respects, by other means, the Lieberkuhn therefore being a device that the microscopist can get along without. It is interesting chiefly on account of its age and history.

The Parabolic Speculum.

This too has gone out of fashion, but it might well be revived for use with low-powers up to the one-half inch, and over large opaque objects. It is a silvered and polished surface of such curvature that parallel rays are reflected from it to a focus on the object, after the apparatus has been attached to the objective, and the mirror swung above the stage. A large object may be examined with all the shadow effects preserved and intensified, and these effects are in some cases exceedingly fine.

Mr. E. H. Griffith has suggested the use of a silver-plated spoon as a cheap and effective substitute for the opticians' finely finished accessory. He winds a clean copper-wire of one-twenty-fourth inch in diameter three times around the base of the objective, bending both ends so that they may reach somewhat beyond the front of the lens. He than cuts a section of about half an

inch from the bowl of a new tea-spoon, and solders the ends of the wire to the convex surface. The wire loop serves to hold the apparatus in position, easily sliding on and off the objective, and being readily bent as the adjustment of the spoon-speculum may require. This is to be used with parallel rays, as is the more expensive but scarcely more effective parabolic speculum supplied by the opticians.

The Vertical Illuminator.

With the vertical illuminator the objective acts not only as an objective but as an achromatic condenser, focussing on the object the light sent through it from the rear, opaque objects being seen, therefore, by surface illumination, and transparent substances by reflection from their inferior surface, the light being forced to act so that the transparent object appears self-luminous.

The apparatus, which was invented by Prof. Hamilton L. Smith, of Geneva, N. Y., consists of a hollow, brass cylinder fitted at one end for attachment to the body-tube, and at the other to carry the objective. At one side a projecting milled-head bears a pin which carries, within the hollow of the cylinder, a disk of thin cover-glass which is to act as the reflector, to throw upon the back lens of the objective the light received through a lateral opening about one-fourth inch in diameter and

opposite the glass disk. At the side of this aperture, a diaphragm is frequently attached so that by it the amount and the direction of the entering light may be altered. As originally devised the reflector was of metal, but this has been replaced by the equally effective thin-glass.

With the vertical illuminator, opaque objects may be studied with high-power immersion-objectives. Yet even with them its use is limited, since the object must be mounted dry and adherent to the cover. It can be utilized for the examination of the surface of blood-corpuscles, diatoms, insect scales, ruled lines, or similar objects capable of being dried without injury, or naturally existing in a dry condition. It is reported that good results have also been obtained in the examination of mucus, pus and liquids containing bacteria, etc.; also in the minute structure of muscle and of nerve-fibres.

To use it, the objective is attached at the lower end and focussed. The light from the mirror is then removed, and the illuminator rotated until the lateral aperture faces the lamp, whose flame should be on a level with the opening, so that its rays may enter and fall upon the glass disk within. By manipulating this disk by means of the external milled-head, the light may be thrown obliquely or centrally on the back lens of the objective, through which it passes to be condensed on the object at the focus, where it will appear as a narrow transverse band. The objective should be carefully adjusted and focussed, and the band of light made as narrow and brilliant as possible. The best condition of the light can be obtained only by experimenting with the lamp, the glass disk and the diaphragm at the lateral opening.

Mr. Adolph Schultze, writing in the "Journal of the Quekett Microscopical Club," with reference to the use of this accessory, says:—After having roughly focussed the lens on the slide, adjust the lamp in a vertical direction so that a line perpendicular to the optical axis of the microscope, drawn through the centre of the aperture of the vertical illuminator, passes through the lowest point of the flame, or just over the top of the wick. Adjust now the reflecting surface of the vertical illuminator on its horizontal axis, so that a distinct image of the flame appears in the field of vision. This image will of course appear brightest, and the definition best, when the narrowest side of the flame is turned toward the instrument, which can be easily ascertained by turning the oil-vessel of the lamp a little round its axis, whilst looking into the microscope. The field is now quite dark, and nothing is seen but a streak of light about a quarter of an inch in breadth, which passes through the middle of it antero-posteriorly. If all this has been carefully attended to, and if a diatom, adhering closely to the cover, is moved into this image of the flame, its markings will appear most beautifully and distinctly resolved, provided they are lying across the path of the light. Various little advantages may be gained by a more careful regulation of the relative heights of the light to that of the aperture of the vertical illuminator, or by shutting off one-half of the aperture of the latter, or by allowing the light to fall on the lower half of the aperture, etc., all of which have for their object to let the light fall on only one-half of the reflecting surface, leaving the other for the passage of the rays from the object to the eye-piece. The image of the flame does not always intersect the whole of the field, and in this case it falls more in the fore part.

By means of this apparatus the lines on the nineteenth band of Nobert's test-plate have been separated, and *Amphipleura pellucida* has been resolved into dots by the proper objectives.

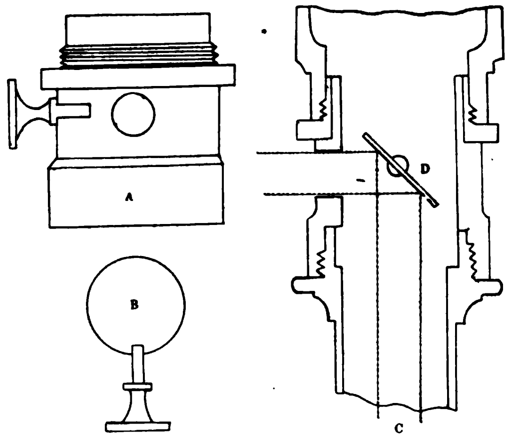


Fig. 13. The vertical illuminator.

It is exceedingly difficult to use, but its effects on the proper objects are remarkable. It is shown in Fig. 13, *A* being the instrument, *B* the milled-head pin to hold the thin cover-glass, and *C* a sectional view as attached to the microscope and objective, *D* being the reflector and the parallel lines the entering and reflected rays.

The Amplifier.

The amplifier is a double concave, or an achromatic concavo-convex lens placed in the tube of the microscope between the eye-piece and the objective, to increase the size of the image formed by the latter, and so apparently to increase the magnifying power. The accessory has long been used in the telescope, and for many years to a certain extent in the microscope. Yet, although known, it did not come into even limited employment until the late R. B. Tolles produced his achromatic amplifier, and even since that time it has not been very extensively used although this achromatic form is immensely superior to the common double-concave lens sometimes employed, and which is accompanied with considerable loss of light and impairment of definition.

Mr. Tolles's lens is so mounted that it may be screwed into the draw-tube. It is said that by its means resolution has been had of the nineteenth band of the Nobert test-plate, which could not be had without it by the same objective, and that it does not necessitate any readjustment of the objective, and only the slightest alteration of the focus.

Dr. G. Devron of New Orleans, in an enthusiastic description of this special form, says:—Every microscopist should possess a Tolles's amplifier, or a similar instrument; its cost is but little more than that of an ordinary eye-piece, and as it may be used with every eye-piece, its possession is equal to having twice as many such glasses; and the possessor of a good, modern objective of moderate power can accomplish with it almost anything that would require an objective of the same grade and of double magnifying power; thus a one-twelfth with an amplifier will do the same work that a one-twenty-fourth would do without the ampli-

fier. Object glasses of high-power are very expensive when well made, and require great manipulative skill for their use, while a medium power of the same quality is not half as expensive, is easily worked and is more frequently needed. Other microscopists do not agree with Dr. Devron, condemning the apparatus for destroying some of the objective's definition.

Personally I have never used Mr. Tolles's or any other amplifier. With it the late Dr. J. J. Woodward of Washington, and Mr. G. W. Rafter of Rochester, N. Y., have obtained excellent results in photo-micrography.

The Erector.

The inversion of the image renders dissection or indeed any manipulations with the compound microscope, difficult to most persons, as they are unable to cultivate readily the habit of moving the hand towards the left when it is desired to have the image move toward the right, or *vice versa*. The opticians therefore offer a prism of peculiar form, so mounted that it may be placed between the ocular and the objective, and by its action erect the image, thus constituting what is called

the erector. Mr. Joseph Zentmayer makes one which is said to interfere very little with the definition of the objective, and Messrs. Bausch and Lomb add a body-tube to their dissecting and mounting microscope in which is an erecting prism.

An anonymous writer describes a home-made erector formed from one of the right-angled prisms which are used for ornament around certain chandeliers. If this be held horizontally over the eye-piece, with the widest face directed from the observer, and the image viewed through it, the object will seem to be in its normal position; and if the prism be held in exactly the right position, the definition will be slightly if at all impaired.

I have experimented with this simple contrivance with objectives up to the half-inch, and nothing above this is ever used in ordinary dissections, and I find that it does all that could be expected of it, and with but little deterioration in the definition. It would not be a difficult task for anyone possessing even a little mechanical ability, to cut off a portion of such a prism and to mount it above the eye-piece, after the cap had been removed, if necessary.

The image may also be erected by the use of an objective placed over the ocular, the screw-end downward, or in the draw-tube above the objective. I have obtained excellent results without much impairment of the definition, by using Messrs. J. W. Queen & Co.'s two-inch objective in the draw-tube with the front lens directed upward, with Spencer's one-inch of 33° on the body-tube. The working distance of the one-inch is thus greatly increased, the magnification reduced, and the field contracted in size, but various manipulations about the stage may be accomplished with the greatest comfort under the combination.

The Polariscope.

This apparatus, so important in the study of crystals and of the structure of rocks, divulging secrets that could be learned by no other means, consists of two prisms of Iceland spar, one placed below the object and called the polariser, the other, the analyser, above it, usually with a plate of selenite on the stage beneath the object. The use of ordinary light may show nothing of the organization of certain bodies, which is at once revealed when the polariscope begins to question it. In the study of crystallography and of petrology it is indispensible. And for the revelation of that perfection and richness of color so appreciated by the normal eye, it is the only means that we have for its exhibition in the microscope.

Polarisation of light was discovered by accident in 1808. Etienne Louis Malus, a French optician, while experimenting with light, happened to view through a doubly refracting prism of Iceland spar, the light of the setting sun as it was reflected from a glass door which was standing open. The phenomenon then seen for the first time he named polarisation, because, on further study, he supposed that certain of its properties bore "some analogy to the opposite properties of the different poles of a magnet," so that this peculiar kind of light was said to be polarised. The supposition, however, was an entirely gratuitous one.

The effect is produced by "light reflected from or transmitted through glass at an angle of incidence of $54° 35'$, or light propagated by only one plane of vibrations." It is supposed that a ray of common light consists of vibrations in all possible planes, but for practical purposes they are considered to be in only two directions at right-angles to each other, polarised light

being that kind in which the vibrations are reflected or transmitted in one plane only, all the other kind of vibrations having by some means been intercepted. Prof. A. P. Gage in his "Elements of Physics," illustrates this by Fig. 14, saying that the action of the

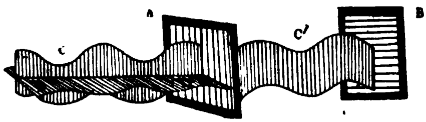


Figure 14. Explanation of polarised light.

tourmaline (the polarising substance used in the experiment) may be compared to that of a grating *A'* in the figure, formed of parallel vertical rods, which will allow all vertical planes, as *C C'* to pass, but stops the planes *D D'* that are at right-angles to these rods. Any plane that has succeeded in passing one grating will readily pass a second similarly placed. But if the second grating *B*, is turned so that its rods are at right-angles to the first, the plane that has succeeded in getting through the first grating will be stopped by the second.

Iceland spar is the substance used for the microscopical polariscope, being a mineral not rarely found in many countries. It is a colorless, entirely transparent carbonate of lime, and capable of being separated, by the proper treatment, into a six-sided solid of a peculiar inclined form, called a rhomb of Iceland spar. From this are made the Nicol prisms, being so named for a Mr. Nicol, an optician of Edinburgh, who first prepared them by dividing these rhombs into two equal parts by a plane passing at a certain angle diagonally through them.

In the undivided rhomb a ray of light falling perpendicularly on the surface is divided into two separate parts, one taking the direction of the original ray, and so named the "ordinary ray," the other being refracted to form what is called the "extraordinary ray," so that any small object looked at through a slice of Iceland spar, will appear to be doubled. Mr. Nicol, by his treatment of the rhomb, succeeded in producing single-image prisms for use with the polariscope, in which there are two, one forming the polariser, the other the analyser, the extraordinary ray alone being allowed to pass, the ordinary suffering total reflection.

The polarising prism is so mounted that it may be attached to the sub-stage or inserted into the stage-opening. It must be below the object, and either it or the analyser must be capable of rotation at the will of the microscopist, but which shall be movable is of no importance. For convenience, the polariser may be used with the sub-stage condenser and below it.

The analyser must be above the object. Whether it is placed in the body-tube or above the eye-piece has some effect upon the intensity of the illumination and the size of the field, but none upon the polarising action. If the analyser is in the body-tube the light is diminished; if above the eye-piece the field is greatly reduced in size, while the amount of light suffers little or no diminution.

When the prisms are applied to the microscope, they should be in such a position, that is, with their polarising planes parallel with each other, that the field shall be brightly illuminated. If it should be dark or only faintly lighted, the prisms are at or near right-angles to each other, and are then said to be crossed and the light may be turned on by rotating one or the other.

In most work with the polariscope it is usually best to use a low-power objective only, which is attached to the body in the usual way, the field illuminated and the object focussed. The polariser or the analyser is rotated and the effect studied. There is, however, nothing in the polariscope to prevent its use with high power-objectives over suitable objects.

When the prisms are crossed at right angles to each other, the field will be absolutely black if the apparatus is perfect, and with the field thus darkened, any transparent object capable of being polarised, as all substances are not, will, when placed under the objective, be lighted and may be exquisitely colored. Yet some objects, although they may show the effect of polarised light when the prisms are rotated, may not be colored. In such cases a plate of selenite is placed beneath it, when it will exhibit at every quarter turn of the prism, complementary colors which will vary according to the thickness of the selenite.

The instrument deserves to come into more general use. It is employed with ease, demanding no complicated or delicate manipulations, and its effects are always pleasing and such as can be obtained only by it. That it is not oftener employed by microscopists is probably due to its cost, and probably to a feeling that its practical usefulness is not sufficient to warrant the outlay; but this is a mistake. It merits careful study.

Drawing the Object.

The microscopist that cannot draw is unfortunate. There are many occasions when to be able to sketch the appearances seen at the moment, is a great convenience, whereas to be compelled to attach the camera lucida to the eye-piece, and to prepare the paper and the light, not only consume time, but may result in the loss of the object if it be a living one. All forms of camera lucidas are intended for use in drawing the outlines only of the object. The shading and the fine artistic finish must be added afterwards. All the devices are attached to the ocular above the eye-lens after the cap has been removed, and considerable practice is required with all the different kinds before they can be used with much success.

The light must be correctly modified or the pencil point will be invisible. This is one of the necessities, and the invisibility of the pencil point one of the difficulties in the use of all these drawing contrivances. The light on the paper should not, as a rule, be stronger than that on the object; it should usually be weaker. If it must be increased, as it must with certain forms, the lamp can be arranged so that it may be nearer to the paper, and a bull's-eye condensing lens be interposed between them, while the illumination of the object may be modified by diaphragms or by increasing the distance between it and the mirror, if the concave face is used. The pencil should be rather soft, with a long, sharp point, whose visibility some microscopists are in the habit of attempting to increase by the addition of a little tin-foil wrapped about it, contending that the bright foil is more easily seen than the graphite pencil point. Others blacken the end of the pencil with india ink, making for this the same claim as for

the tin-foil. The proper illumination seems to be more important than any of these aids, and its careful regulation better than any addition to the pencil point.

Mr. T. Suffolk describes, in "Science Gossip," his method of drawing without a camera lucida of any form. He places on the diaphragm of the eye-piece a convex lens of shallow curvature, upon the surface of which is a grating ruled in squares, the lines being about one-twentieth of an inch apart. The drawing, which is made on paper also ruled in squares, may then be enlarged or reduced after the well-known method employed by draughtsmen. "The process also possesses the additional advantage of requiring no change in the position of the microscope, as is the case with the camera lucida, and can be used for a long time without any of the strain on the eye inseparable from the use of instruments where the image and pencil point are viewed through the divided pupil of the eye."

The Thin-glass Reflector.

The simplest form of all the appliances intended for the microscopist that cannot draw free-hand, is a thin-glass cover attached in any convenient way to the ocular, so that the image shall be received upon its

upper surface at the proper angle, which may be determined by experiment, but which is usually 45 degrees if the body-tube becomes horizontal when inclined, as it will not become on all stands. The microscope is depressed into this horizontal position, the paper arranged on the table beneath the eye-piece, and while the pencil is seen through the thin cover-glass, the object appears to be projected on the paper, where the pencil draws the outlines.

Mr. T. B. Jennings has described the following simple method of mounting the reflector. In a flat cork he cuts a central opening large enough to pass over the mounting of the eye-lens, and just below this aperature he makes an incision to receive the cover-glass so that it may stand at an angle of 45°.

Beale's Neutral Tint Reflector.

A form similar to the thin-glass disk but differing in being tinted a neutral color, is Beale's reflector. It is employed quite extensively, more so than the colorless cover-glass, but in the same way. It is made by opticians generally, being intended to slide over the mounting of the eye-lens, after the cap has been removed.

A Simple Mirror-reflector.

An anonymous writer recommends a reflector to be made as follows. Take a small portion of the silvering, about one-sixteenth of an inch in diameter, from the back of a mirror, where there should be a thick coating of paint on the amalgam to support it, or it will not break off. This small amalgam reflector is to be mounted with cement on a piece of watch-spring at the proper angle. The spring is bent round and fixed to a brass tube fitting over the eye-piece, so that the reflector may stand about one-fourth of an inch from the eye-lens and central with it. On looking into it, the object on the stage is seen and appears to be projected on the paper below.

The objection to all these simple forms, especially to the neutral tint reflector and its imitators, is that they not only invert the image, the top appearing at the lowest part, but seem also to turn it over, the left-hand side being transferred to the right-hand. To finish a drawing thus inverted and reversed is difficult. The microscopist will be sure to lose his way when, after glancing through the microscope for the details, he attempts to add them to his sketch. With the neutral tint the field is also very small. To see the whole of the field at one time is impossible.

Wollaston's Camera Lucida.

One of the earliest forms of drawing-prisms, and one of the best, is the four-sided accessory known as Wollaston's camera lucida. It is so mounted that it slides over the eye-lens, after the cap has been removed, the image being apparently projected on the paper upon the table, and seen in its proper position, since it has been twice reflected by the prism, the pencil and the paper being seen direct, that is, without reflection. The acute edge of the prism bisects the pupil of the eye, one-half receiving the rays from the microscope, the other half those from the paper and the pencil. For this reason it is at first somewhat difficult to use, but a little practice soon conquers it. Like all similar kinds of apparatus it is used with the left-eye closed.

The microscope must be in a horizontal position, and the light on the drawing-surface should be much stronger than that on the object. When the illumination has been properly adjusted the prism can be used with great facility, and most satisfactory drawings made with it. If the field projected on the paper below the prism is not evenly illuminated, or if it is colored at the margins, the camera lucida should be altered by rotating it slightly, or by changing its position in relation to the eye-piece. When the object is focussed, and the field as seen on the paper is properly illuminated, the eye is kept steadily over the acute edge of the prism while the pencil sketches the outlines of the image. The secret of success is to keep the eye motionless. If it turns ever so slightly the pencil point will mysteriously disappear, in which event it should be held immovable until the eye again finds it.

If the microscopist is accustomed to the use of spec-

tacles he will find them an advantage when drawing with any kind of camera. One of the troubles experienced by some that use spectacles is that the pencil cannot be seen at the same time with the object when the spectacles are removed. Those whose eyes are perfect occasionally have the same trouble. This may be imperfectly remedied by using a very low-power convex lens placed immediately below the prism, between it and the paper. By its use the rays from the drawing surface are given the same degree of divergence as those from the camera. Some opticians attach this lens movably to the apparatus, so that it may be utilized or not as the microscopist may desire.

The size of the drawing will depend upon the distance between the paper and the prism, increasing with that distance, so that almost any enlargement may be obtained. Immense diagrams may be made, according to Dr. L. S. Beale's method, by placing the paper on the floor, or what may be more satisfactory for ordinary purposes, by raising the microscope on a box or other support above the table on which the drawing is to be made.

The Abbe Camera Lucida.

Perhaps the most prominent camera now offered by the opticians is that of Professor Abbe. It consists of two prisms cemented together so as to form a cube,

one of the contacting hypothenuse surfaces being silvered, or gilded, with the exception of a small spot in the centre, and slightly removed from the prism so that there is a thin film of air between them. A plane mirror at the end of a lateral arm reflects the rays from the pencil and the paper to the silvered prism, whence they are reflected to the eye.

This camera may be used with the microscope either vertical or inclined, the best effects being obtained when the body-tube is somewhat inclined, as the distortion of the image is then less than when the microscope is vertical. When the prism is at one side of the instrument and the paper at one side of the microscope-foot, the distortion is so great that a special drawing-desk must be used and inclined at an oblique elevation.

It is to Prof. S. H. Gage, of Cornell University, that we owe a more complete knowledge of the distortion produced by this camera and of the best means of overcoming it. When using this form the aperture in the silvered surface of the prism must be exactly in the optic axis of the microscope and at just the right distance above the eye-piece. If the field as seen through the camera is not evenly illuminated, or if the entire field can not be seen at once, the prism has not been properly placed, and must be re-arranged by altering the little screws in the collar of the instrument. The mirror of the Abbe cameras which I have seen is permanently fastened at an angle of about 45°, so that the microscopist is relieved from all manipulations of this part, except to slide it to and fro on the mirror-bar so as to select the portion of the drawing paper or of the table that is to be reflected. As Prof Gage says in reference to the use of all forms of camera lucida: "In order that the picture drawn . . . may not be dis-

torted, it is necessary that the axial ray from the image on the drawing-surface shall be at right angles to the drawing-surface." And that the end of the drawing board shall be in a plane parallel with the stage of the microscope; the mirror must also have its edges parallel with the edges of the drawing-board.

If the mirror of the camera be movable on its axis, when the microscope is inclined the mirror must be manipulated so as to prevent the distortion otherwise inevitable. The general rule in these cases, again quoting from Prof. Gage, is to raise the drawing-board twice as many degrees toward the microscope as the mirror is depressed below 45°. With the mirror at 45° the drawing-surface should be horizontal; with the mirror at 40° the drawing-surface should be elevated 10°, and with the mirror at 35° it should be elevated 20° toward the microscope. Even in these conditions there will be distortion from front to back unless the drawing-board is again elevated in the proper position. To accomplish all these points Mrs. Gage has devised a drawing-board shown in Fig. 15. It is to be used with

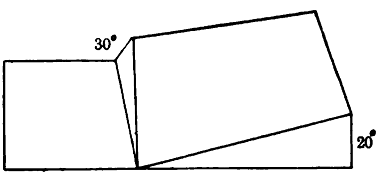


Figure 15. Mrs. S. H. Gage's drawing-desk for the Abbe camera lucida.

the mirror at 35° and the microscope inclined at 30°. For other positions of the camera-mirror and of the microscope, a drawing-board may be devised with the proper surfaces by Prof. Gage's rule already given.

Messrs. Bausch & Lomb make a camera lucida to be used on the microscope when inclined, with which they claim that the pencil-point is well seen, and the distortion less than with even the Wollaston prism. I have not seen it.

The Grunow Camera Lucida.

In this device, which is made by Mr. J. Grunow, of New York, the plane mirror of the Abbe camera is replaced by a rectangular prism to reflect the rays from the drawing-surface. It consists of three rectangular prisms, two forming a cube, one surface being silvered or coated with gold, and having a perforation in this deposit essentially as in the Abbe form, the third prism being intended to reflect the rays from the paper. The apparatus may be used with the body-tube inclined or vertical, giving, it is said, a very distinct image of the pencil and the object. "A portion of the surface of the work-table of the size of about twelve or fifteen inches is projected into the field of view, so as to be distinctly and clearly seen with the object on the stage." The camera must, however, be especially fitted to the eyepiece with which it is to be used. I have not seen it.

Live-boxes, Growing-cells, and other Accessories.

On the upper left-hand corner of many microscope stages will be noticed a small hole intended to receive the stem of the stage forceps, a piece of apparatus sometimes furnished with stand. It was more frequently added by the older opticians than it is by those of the present day, and it was oftener used by the older microscopists than it is by those of the present time.

It consists of a delicate forceps opened by a slight pressure on a projecting pin, closing by its own elasticity, and with a long handle having universal motions by means of a ball-and-socket joint, or by some other way. It is used to hold small insects or opaque objects under the objective, generally a low-power, so that they may be examined in all their parts and in all positions.

The Mechanical Finger.

The microscopist that does much mounting soon feels a desire to produce some preparation to show his skill in the manipulation of small objects, as well as the adaptability of small objects to the formation of beautiful slides. Butterfly scales are arranged into bouquets of the most delicate and gorgeous hues; diatoms are laid down in intricate geometrical patterns and figures that are a joy to the eye, or they are selected from a mass of dirt, and lifted into the light and the purity of another slide, where the expert microscopist studies them with increased pleasure when he recalls the source

whence he took them. All such delicate work is done by the use of a mechanical finger, which is essentially a fine bristle, or a filament of spun glass, attached in some way below the objective. The filament picks up the little object while the microscopist's eye is at the ocular, holds it suspended in air until he moves a slide beneath it, when it gently lowers the selected specimen into the spot prepared for it, and returns under the microscopist's intelligent guidance for another similar load. In this way, after repeated visits to the source of supply, the mechanical finger produces exquisite arrangements of diatoms, of insect scales or of other minute objects.

To use even the simplest mechanical finger demands much preliminary practice, yet those that have mastered the apparatus seem to have little difficulty in producing the wonderful results just referred to.

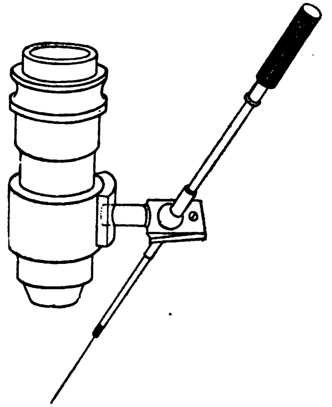


Fig. 16. E. A. Apgar's mechanical finger.

An uncomplicated form which has been very successfully used by its inventor is that shown in figure 16,

having been devised by Mr. Ellis A. Apgar, who at my request has thus described it.

It is constructed out of the stage forceps, the forceps part of that appliance being removed, and in the end of the arm a minute hole is drilled one-eighth of an inch deep. Into this is inserted a bit of fine spun-glass or a cat's whisker, and kept in place by wax. A wooden collar is fitted to the front of the objective, and in the wood is bored a hole of the proper size to receive the stem of the forceps, and from which it may be removed at pleasure. Thus for a few cents an almost valueless implement may be converted into one that is often useful, and in the hands of an expert, one that is capable of performing marvels in the preparation of arranged diatoms.

The tube through which the stem passes, together with the socket-joint give the operator complete control of the point of the hair or of the glass filament, enabling him to place it in exact focus or not, as he may desire, and by the use of the rack-and-pinion movement of the body-tube with one hand, and the shifting of the stage with the other, the minutest diatoms may be selected and placed wherever desired; delicate objects may be spread out and arranged, and fine particles of dust may be removed before the cover-glass imprisons them.

The slide intended to receive the diatoms or the scales in patterns, is usually slightly coated with a thin and weak solution of gum arabic, in which is a little acetic acid, and allowed to dry. The object being deposited in the proper place and position, the slide is gently breathed upon, the moisture of the breath softening the gum sufficiently to allow the object to adhere, the thin film of dried mucilage being invisible when the Canada balsam is added.

The Animalcule Cage or Live-box.

It often happens that the microscopist who is working with pond-life needs some means of preserving the life of the aquatic creatures longer than is possible with the ordinary cement cell and the cover-glass. There are numerous life-slides, or growing-cells, well adapted to this purpose, but the animalcule cage of the optician has the additional convenience of being usable as a compressorium as well as a life-slide. It is somewhat inconvenient however, because it is heavy, difficult to clean, and as ordinarily made, almost unusable with high-power objectives. With comparatively large objects and low powers it is commendable.

Mr. E. J. Whitney has suggested a very cheap and effectual substitute for this rather expensive piece of apparatus, which he makes by obtaining at the hardware store, a full set of about a dozen ferrules of graduated sizes, fitting snugly one inside the other. Take any two which fit well together and cement the smaller one, large end down, to the centre of an ordinary glass slip. To the top of the ferrule cement one of the thickest cover-glasses that will fit. Now take another cover-glass that fits inside the larger ferrule, and cement it to the inside at the top. The box is now complete, and all that remains to be done is to slip the larger ferrule over the smaller.

Life-slides or Growing-cells.

Some of these numerous devices are complicated and expensive, and are to be obtained only from the optician. Others are simple, easily made by the microscopist himself, and are as praiseworthy for their working qualities as those offered by the dealers. The purpose of every one is to supply enough air to keep the imprisoned plants and animals in good condition, so that their life-processes may be performed as in freedom.

This part of the problem is not so difficult, but to supply the animals with the proper kind and amount of food, and to imitate pretty closely the environment which they must have or suffer, are not so easy of accomplishment. No life-slide has successfully solved these parts of the question. All forms succeed for a time, some longer than others, but all fail within a very limited period. Those animals whose life-history is begun and finished within a few hours, or a day or two at most, can be accommodated, but those which develop slowly and live comparatively long, give the microscopist a difficult and troublesome subject to consider.

With microscopic plants the question is no more easily settled. They die as readily as the animals, even after they have received the most careful attention. They refuse to continue their life-history. Their chlorophyll grains fade, and slowly group themselves together near the centre of the cell; the protoplastic granules increase in number and swarm and quiver in their ceaseless pedetic dance, and the fungi come to envelop the whole in a fluffy winding sheet, which, however interesting at the proper time and place, is not acceptable in one's growing-slide.

There is never any difficulty in cultivating microscopic fungi of a certain kind. They cultivate themselves, and

force themselves on the notice of the microscopist that has them always with him. They will even grow and flourish and be happy in the horribly astringent solution within the alum-cell of the oxy-hydrogen microscope.

The simpler the life-slide the better the results, and the hastily-made and home-made productions are often more satisfactory than the elegant and elaborate contrivances offered by the dealers.

For my own purposes I take for covers for such cells large thin-glass squares only. There are several advantages to be had in their use in this connection over that of thin circles, one being the facility with which the water supply can be renewed. By carefully adding, with a camel's-hair brush, a drop of fresh water at the corner of a large square cover projecting beyond the cement cell, the fluid will usually flow under so gradually that the object, even a minute Infusorian, will not be moved from the field, the inward rush of the current being tempered by the cement ring. This supply can be easily added by one hand holding the wet brush while the eye is intent at the ocular, the secret of success here being in not having too large a brush and in not filling it too full of water. At the beginning of daily evening work the brush is wetted and thrown on the table to become thoroughly moistened, when a single dip into the tumbler of water, with a slight shake to prevent dripping, takes up enough, although some pressure of the brush against the slide may be needed to squeeze out a small drop. It is better to make several journeys to the tumbler than to lose the object. A dipping tube adds too much at once, and cannot be so readily controlled as a brush.

In studying the morphology of minute animal organisms, I use only a shallow, shellac cell with about one-

fourth of the ring scraped away from both the upper and the lower margins, thus leaving two curved supports for the square cover, one on each side. The dia-

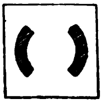


Fig. 17. A simple life-slide.

gram shows the arrangement, the shaded parts representing the remnants of the cell. This gives the enclosed drop, with its animal life, plenty of air, and facilitates the application of the wet brush at the point where the square cover projects beyond the lateral cell-wall. In this simple affair I have frequently kept Infusoria and other small creatures alive and well from early in the evening until after midnight, and when compelled to leave them have washed them into the aquarium in as good condition and as lively as when first imprisoned. Here the secret of success consists, I think, in leaving enough of the cement ring to support the cover properly and to lessen the force of the inflowing water-supply, and also in having the cell shallow or deep according as the animals are microscopically small or large. Much depends on the depth of the cell in all cases. A comparatively large Infusorian, a Rotifer or a *Chætonotus* can be injuriously hampered in its movements and in the proper performance of its functions, by a cell of insufficient depth, and a good objective can as the reader knows, be greatly hampered in its functions by a cell of too great depth.

If it is desired to convert this or any other slide of the kind into a growing-cell, it is done by the well-known method of placing the slip across a small

saucerful of water with a doubled and twisted thread of sewing-cotton in close apposition with the edge of the cover, both ends of the thread hanging freely in the water. The liquid will flow up and supply that lost by evaporation, provided the water is always in contact with the lower surface of the slide. This "dodge" is successful for a few days, but it always ends badly, as the salts in the water will crystallize at the cover-margins and cut off the oxygen supply.

It often happens that the conditions and the environment are such that an immense number of minute Infusoria, all belonging to the same species, are suddenly developed in the aquarium, infusion or maceration, and it becomes interesting to isolate a few to study their life-history. Such an advent of Monads, *Heteromitæ* and other similarly minute creatures is not rare. For the study of such truly microscopic objects I have devised a simple life-slide, describing and figuring it in "SCIENCE GOSSIP" for January, 1894. To make it, cement with Canada balsam in the centre of a slip a thin glass disk one-fourth inch or less in diameter; use a one-sixteenth inch cover-glass if possible. In the latter case, then take a glass, or zinc or other kind of ring with a quarter-inch aperture, break a small piece from one side, and fasten this broken circular band about the central disc. From another ring with a three-eighths inch or larger aperture, break a piece as before and cement this broken band around the inner ring so that its broken part shall be opposite the unbroken curve of the latter, and with a thin square cover, the cell is complete, the depth depending upon the difference in the thickness of the outer rings and the central circle.

To use, place on the central disc a small drop of the

water containing the organisms to be kept alive, and over it arrange the square cover, taking care to prevent the water from overflowing into the inner annular space. With the camel's-hair brush carefully, and in small quantities, add fresh water at the top or the side of the square, never at the bottom or near the opening in the outer ring. It will be found that the water will flow between the square and the upper surface of the exterior ring, will enter through the break in the latter, partly filling the outer annular space, and by capillary attraction will occupy a part of the vacancy between the

Fig. 18. A simple life-slide.

cover and the interior ring, (as shown by the diagonal lines in the diagram, Fig. 18), but unless too much water is used or it is supplied in too great quantities at once, it will not pass through the opening in the inner ring, thus leaving an abundance of air to supply the animals under observation. The imprisoned air at once becomes saturated with moisture, as is evidenced by the fogginess of the cover; the central drop cannot evaporate and the external water will not come in contact with it, if care be taken in filling the slide and in supplying that lost by evaporation. To admit entirely fresh air the water can be drawn off by bibulous paper, or allowed to evaporate, without in any way disturbing the central drop. The reader must remember however, that the cell is intended for only the smallest of microscopic animals, with which it is entirely successful.

Logan's Life-slide.

Mr. Logan's device consists of a strip of wood with a central perforation, in which is fitted a glass cell formed of a thick platform surrounded by a deep groove. The object is placed in a drop of water on the central platform, and a cover-glass cemented over the whole with wax. A ring of sheet-wax is applied to the projecting ring around the groove, and the cover is fastened down by running a warm wire around the edge to melt the wax, the thickness of the cell, that is, the distance of the cover-glass above the central platform, of course depending upon the thickness of the wax used. The air confined in the groove by the cover will be enough to supply the microscopic creatures for a long time.

Mr. Logan's slide is objectionable because it is so heavy, the central disc being so exceedingly thick that no sub-stage condenser can be focussed through it, and the annular depression so deep that the glass sides affect the light in an undesirable way. For comparatively large aquatic objects to be examined with a low power it is useful, but I find my own modification of it better for more delicate work.

A small square, cut from glass of any desired thickness, is cemented with Canada balsam to a slip, and surrounded by a thick, glass or zinc ring so as leave a wide space between these parts. On the ring place a ring of wax and, after the object has been arranged on the central square, cover the whole with a thin cover and cement it fast by running a warm wire around the edge to melt the wax. A small drop of water may be placed in the annular space if desired.

A diagram of this slide is shown in Fig. 19. The reader of course understands that the thickness of the

slip and square, and the depth of the cell, must be determined by each worker according to his needs. For myself I have them as thin and shallow as possible.

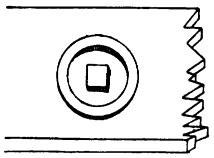


Fig. 19. A simple life-slide.

The secret of success here is to be sure that the joint between the ring and the slip is air-tight, and to secure the cover firmly, using an abundance of wax.

In this simple contrivance *Hydra viridis* has lived uncomplainingly for an entire month, and for four weeks a *Chironomus* larva has existed, with no food except what may have accidentally been in the water, and no air except that within the annular space; not only has the same larva lived in that confined place, but it there ceased to be a larva, and became the perfect insect, of course soon dying for the want of air, and on account of its inability to expand and to dry its wings. In the same form of life-slide, with an abundance of algæ and of infusorial creatures, the rotifer *Furcularia* has thrived and built her mucilaginous home and deposited her eggs, being contented there for a whole month and apparently willing to stay another.

For showing living Infusoria, Rotifers, *Chætonoti*, aquatic worms and other animals at microscopical exhibitions, nothing could be more satisfactory than Mr. Logan's slide. With it the writer has kept a quantity of Turbellarian worms well and active until the small hours of the morning. In this instance the slide was prepared for an exhibition, so hurriedly and so late that the cement was not dry before the opening hour

arrived, but an external application of the thin and rapidly-drying Brown's rubber-cement made all tight, and apparently not unpleasant for the worms.

Hitchcock's Moist Chamber.

Mr. Romyn Hitchcock has used and recommended two forms of simple life-cells. One is prepared by inverting a small salt-cellar in a dish of water to serve as a support to the specimens, a tumbler being inverted over the whole. The objects are placed on glass slips, made by cutting an ordinary slide across the middle, and covered with thin glass.

The second plan the inventor thinks the more desirable. In this a piece of glass four inches square is placed on a support so that it is about on a level with the top of a dish to hold water, an ice-cream saucer being used by the inventor. A piece of blotting-paper is then placed on the glass, and the edge allowed to dip in the water. Objects to be examined are placed on large cover-glasses, and either protected with a smaller cover, or left exposed. These cover-glasses are laid on the blotting-paper with watch glasses above them. A single large watch-glass may be used, or a number of small ones, one for each specimen. Objects can be kept fresh and moist in this way, with far less trouble, Mr. Hitchcock says, than by any other method that he has tried.

Beale's Growing-cell.

In Fig. 20 is shown a contrivance almost as uncom-

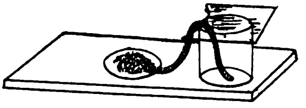


Fig. 20. Beale's growing-cell.

plicated as the preceding, taken from Beale's "How to Work with the Microscope," and used by that microscopist with much success. A small piece of glass tube is fixed to an ordinary slip to serve as a reservoir to supply the water. It is covered with a piece of thin glass, a small opening left at one side being sufficiently large to allow a fine thread of silk or cotton to conduct the water from the reservoir to the specimen placed in the centre of the slide. I have used this contrivance with considerable satisfaction.

H. L. Smith's Growing-cell.

This is a very efficient cell made upon the old principle of the bird-fountain. It has been described by the author as follows:

The whole slide is a trifle more than one-eighth of an inch in thickness, and consists of two rectangular glass plates, three by two inches, and about one-twenty-fifth of an inch thick, separated by strips of the same thickness cemented to the interior opposed

faces, as shown in Fig. 21. This closed cell, ulti-

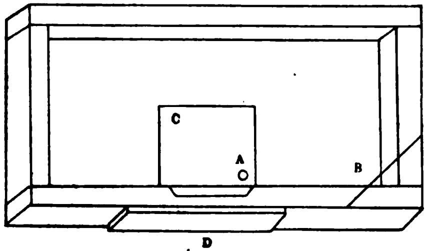


Figure 21. H. L. Smith's growing-cell.

mately destined to be filled with water, is not of such thickness as to prevent the use of the achromatic condenser, a very important requisite. The upper plate has a small hole, *A*, drilled through it, and one corner removed, as at *B*. A small strip of glass cemented below prevents the thin glass cover over the object from slipping. Another strip is cemented on the lower side of the cell at *D*, but not extending as far as the removed part at *B*. The object of this is to prevent the water in the cell from being removed by capillary attraction, in case the slide in the neighborhood of *B* should be a little wetted. This strip is not, however, absolutely necessary.

To use the slide, fill the space between the two plates with clean water, introduced at *B*, by means of a pipette, and also place a drop on *A*, to remove the air. The object being put on the top of the slide and wetted, is now to be covered with a large square of thin glass, *C*, at the same time covering the hole *A*. The slide can now be placed upright, or in any position, and no water can escape, but as it evaporates from under the cover, more is supplied through the hole, *A*, and from time to time an air bubble enters at *B*; thus a constant

circulation is maintained. A cell of the size named will need replenishing only about once in three days, and this is readily effected without disturbing the object. I have been enabled, Prof. Smith continues, to make observations by means of this slide, which it would have been very difficult, if not impossible, to have made without it.

The cell is not well-adapted to the study of minute animals, if the examination is prolonged for any length of time, unless the aperture in the cell be exceedingly small, otherwise the active creatures will surely discover it and pass through it into the reservoir. They will often increase greatly there, but they are then always beyond the reach of any but the lowest-power objectives. For algæ, desmids or other still-life the slide is commendable.

Sternberg's Culture-cell.

A simple form of culture cell is described by Dr. Geo. M. Sternberg, as a member of the Havana Commission for the Investigation of Yellow Fever. It is made by drilling an opening about one-fourth inch in diameter through the centre of a slip, around which a very thin circle of cement one-half inch in diameter, is turned on one side of the slip and a thin cover attached to it by gentle pressure. When the cement is thoroughly dry, the cell is ready to receive the drop of blood or other

fluid to be observed. This is placed in the bottom of the cell, Fig. 22, which shows the slide in section, and

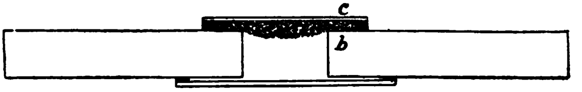


Figure 22. Sternberg's culture-cell.

flows by capillary attraction into the space between the thin cover and the slide until it extends to the circle of cement. Thus there is a thin stratum of fluid between the points *b* and *c* which may readily be examined by inverting the slide, and bringing the objective to any point between the central air-chamber and the cement circle. Finally, the cell is closed by fastening a large thin-glass circle to the opposite surface.

Strassburger's Moist Chamber.

The inventor describes this to consist of an ordinary slide, upon which is placed a ring of pasteboard moistened with water. The object which is to be observed and kept alive, is placed in a drop of water on a cover-glass and inverted over the pasteboard chamber, the cover being made to adhere to the cell by pressure. The evaporation of the water is greatly retarded, if not entirely prevented, so that in this simple manner Prof. Strassburger has kept *Spirogyra* in conjugation alive for several days. By moistening the pasteboard from time to time the cover will remain attached indefinitely.

Deby's Cell for Bacteria.

This is a three by one inch slip, having a glass ring with ground edges cemented to it to form a cell. A small hole is bored through the slip inside and near the edge of the cell. The objects are placed with a very minute drop of water on a thin cover, which is inverted, and attached to the top of the cell by a little lard. The slip is then laid upon another of the same size, but not perforated, and a couple of India-rubber bands are passed over the ends. One end of this arrangement is then placed in a little water, which, by capillary action, will occupy the space between the two slips, and by evaporation will rise into the cell and prevent the drying up of the minute drop on the cover. By this contrivance a drop of water no larger than a pin's head can be kept of nearly the same size for weeks together, and the development of bacteria, or other minute organisms, retained constantly under observation.

M. Deby has also described what he considers to be a simplification of the foregoing. Take a slip and make in its centre a circular opening ½ inch in diameter; lay it upon a slide not perforated, and bind the two together by rubber rings. Grease the upper slip for a short distance around the opening, arrange the object on a thin cover, adding to it another cover ¼ inch in diameter, which will adhere by capillary attraction, and invert the whole over the central aperture. When not under observation place in a shallow vessel of water, as in the original.

Pagan's Growing-slide.

The Rev. A. Pagan has devised the following for the study of rotifers, algæ, and other microscopical organisms needing a frequent change of water. He states that the results obtained with it were remarkable. It may be kept constantly on the microscope stage, if desired.

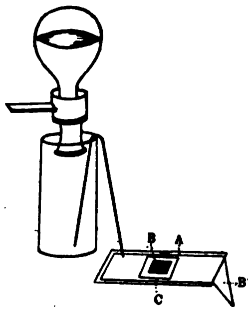


Fig. 23, Pagan's life-slide.

It consists, as shown in Fig. 23, of a slip *A* slightly longer than the stage, so that it shall project a little at both ends. On it is placed a piece of blotting-paper which leaves only the margins of the slip free, and a hole is cut in the centre of the paper, *B C*, and at one end is the triangular prolongation, *B'*, which is bent downward close to the slide. Water is then drawn from the vessel, *D*, by means of the capillary tube, *E*, and drops on the blotting paper. The tube should be only wide enough to allow one drop to fall every twenty seconds, the water being drained off by the triangular prolongation. An inverted flask, *F*, may be filled with water, and so placed that its mouth shall just touch the surface of the fluid in the tumbler, and keep the level of the water constant, thus ensuring the regular escape of drops from the capillary tube; or to simplify the apparatus, this vessel may well be omitted.

Slack's Tubular Live-box.

Mr. J. H. Slack makes a tubular cell for the examination of the mouth-organs of insects. He takes a small homeopathic phial about half an inch long, and a quarter of an inch wide at the mouth. This is inserted into a hole cut in a wooden slip, the rim of the bottle preventing it from falling through. Another wooden slip has a hole through it of larger diameter, and on the top is cemented by shellac a thin glass cover. This slip is laid on the other, the glass cover forming a lid which closes the bottle, the whole being held in position by a rubber band. A little cotton wool is put into the bottom of the bottle to suit it to the length of the fly, which must be inserted mouth upward, and kept moderately near the cover-glass, upon which a drop of syrup is placed. Flies will readily feed in this position, and they are sufficiently limited in their power of lateral motion to be easily kept in the field of the one-inch or of the one and one-half inch objective.

This might be modified by cutting off the bottom of the bottle so as to make a tube of it. The fly could then be introduced, after the cover-glass had been arranged, and in the proper position with its mouth uppermost. It could thus be gently forced to ascend to the desired place by forcing the cotton wool in behind it.

There are many other forms of life-slides or of growing-cells, but these will be enough to give the reader an idea of what is needed, and of the simplest way to accomplish the desired results. The less complicated the apparatus, the better it will be.

THE END.

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